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HIGH INTENSITY DISCHARGE (HID) SOLID STATE BALLAST PROGRAM PHASE I FINAL REPORT

W.R. Alling

September 1980

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HIGH INTENSITY DISCHARGE (HID) SOLID STATE BALLAST PROGRAM

PHASE I FINAL REPORT

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1.0 SUMMARY

As part of the DOE-sponsored effort to develop energy-efficient sources of lighting, Luminoptics Corporation has developed a solid-state ballast to operate a 200-watt high-pressure sodium (HPS), high-intensity discharge (HID) lamp. The performance of six ballasts has been measured by Luminoptics and by an independent testing laboratory (Industrial Testing Laboratories of Berkeley, California).

In this report, HPS lamps operated at high frequency with solid-state ballasts are compared to the same lamps operated at 60 H_Z with conventional core-coil ballasts. The major improvements that the solid-state ballasts show include a 20% increase in system efficacy and a regulated, constant wattage input to the lamps. In addition, the solid-state ballasts can safely dim the HPS lamps over a wide range of light levels.

Given all of the above improvements, these HPS systems may consume as much as 50% less energy than core-coil systems. In addition, both the lighting designer and user acquire a flexibility not previously available.

Measurements of the flicker produced by 60 H_Z and 25 KH_Z operation of the HPS lamps indicate that solid-state ballasts reduce flicker from 70% to less than 1%. Thus, when the lamps are operated with solid-state ballasts, the stroboscopic effects common from HPS lamps are eliminated, thereby reducing eye strain and perhaps increasing productivity for workers who operate rotating machinery.

A cost analysis indicates that when the annual volume of production nears 100,000 units, the return on investment (ROI) can exceed 23%.

While these ballasts should quickly be accepted by both designers and users, this assessment of performance identifies several circuit design areas that should be addressed in the second phase of this study in order to achieve a commercially viable system.

2.0 INTRODUCTION - BACKGROUND AND HISTORY

High intensity discharge (HID) lamps and ballasts account for a significant portion of electrical energy consumed in the United States.

Each year an estimated 15 million ballasts are sold to the commercial/industrial and municiple market and upwards of 50 million units are installed in the U.S.A. These ballasts consume approximately 50 billion KWH per year or the equivalant of 112,430 million barrels of oil at the point of generation.

Fortunately, HID lamps are utilized mostly at night during off peak utility hours. Total consumption accounts for less than 1.2% of all electricity consumed and less than 25% of the energy consumed during the period the lamps are utilized.

In recent years there has been an increase in the number of HID lamps utilized indoors because of increased lamp efficacy that has provided illumination more economically. As these types of lamps are utilized , their use can have a further impact on electrical capacity and supply. The investigation of ways to operate HID lamps more efficiently is a legitimate concern.

Luminoptics Corporation (formerly Stevens Luminoptics Corporation) has been engaged in a Research and Development program since 1974 to develop an energy efficient solid state high frequency ballast for fluorescent and HID commercial/industrial applications. Early investigations disclosed that an electronic high frequency ballast could, with proper design, improve the efficiency of the existing ballast lamp system while at the same time improving the quality of light. In addition, these new systems can provide the professional lighting designer and/or engineer an unprecidented flexibility with regard to the practical implementation of a quality and performance oriented lighting system.

The Company has developed and tested solid state ballasts for both fluorescent and HID applications. In the fluorescent area, the Company has six commercial or government qualification installations either now installed or about to be (as of September, 1980). Large scale production of various fluorescent ballasts is to begin in early 1981.

3.0 TASK I - PROGRAM PLAN

Task Statement: The purpose of this Task is to prepare a detailed working plan for the program and includes the following:

A. A detailed project schedule utilizing DOE Form 534.

B. Indicate critical milestones on the project schedule.

C. Definition of personnel assignments for each task along with sub-task definition when said tasks are lengthy.

D. Allocation of costs per task on appropriate reporting forms (DOE Form 533) and also on the basis of major expenditures such as; direct materials, labor, travel, overhead, etc.

The Task I report was prepared at the beginning of the contract and submitted to LBL. This Task Statement became the "working" document from which contract performance was judged. Accordingly and because of the nature of this Task Report, it is not reproduced here. It is, however, public information and is available upon request.

4.0 TASK II - PERFORMANCE CHARACTERISTICS

4.1 Task Statement:

A. Construct sufficient engineering prototypes for internal testing and delivery of six (6) units as specified in Task V-A.

B. Measure performance of 200 Watt HPS Lamp and Ballast (both conventional and solid state) on the following parameters:

1. Input power
2. Lumen output as a function of center voltage plus or minus 10%.
3. Stroboscopic effect.
4. Record conditions of measurement (time, temp. etc.).
5. Wave shapes (ballast input, lamp input).
6. Compare system efficiency with standard core coil ballast.
7. Define required heat sinking and ambient safe operating conditions for ballast.

C. Prepare preliminary ballast specification (solid state) including the following:

1. Performance
2. Suggested test proceedure.

D. Discuss ballast performance with regard to its implications upon lamp and system performance.

4.2 Ballast Construction; A total of six ballasts were constructed to support the requirements of this contract. Details of the manufacture and test of the units are included in Section VII of this report.

4.3 Performance Measurements, Solid State/Conventional; The peformance parameters defined in 4.1 were measured for both the conventional and the solid state ballast. For the conventional ballast testing an ITT model P33353/24349, 200 Watt, 277 volt, HPS ballast was utilized along with standard 200 watt HPS lamps which were purchased locally out of distributor stock. Two brands of lamps were utilized which are designated Brand X and Y for convenience. The ITT ballast was selected because of it's relatively short delivery time and because it was felt that it represented a better class of ballast with good performance characteristics. Performance testing was performed by Luminoptics Corporation, Industrial Testing Laboratories of Berkeley, California, and Lawrence Berkeley Laboratories.

There is good agreement between the testing conducted by ITL, Luminoptics Corp. and Lawrence Berkeley Laboratories, but not necessarily exact correlation between test data. This is due to the differences in test methods and equipment employed by the organizations. In most instances ITL found that the performance of the solid state ballast was better than was measured by in-house testing except in one instance which is explained as a preamble to the ITL report which is included as Appendix A. It should also be noted that ITL was limited to testing six solid state ballasts, two lamps, and one conventional ballast whereas Luminoptics tested over 18 lamps and two conventional ballasts.

Figure 4-1, Specifications, and 4-2 Summary of Key Technical Characteristics define the basic capabilities of the solid state ballast. Figures 4-3 and 4-4 are graphs which depict the performance comparisons between the solid state and conventional ballast.

4.3.1 Power Input VS Power Output: Figure 4-3 A and B shows the performance of the conventional ballast under changes in (lamp) impedance for the rated line input voltage $\pm$ 10%. Figure 4-4 A and B shows the same parameters for the solid state ballast. The load ohms represents the typical impendance range of the HPS lamp. These graphs depict the change in ballast output wattage over the load impedance range (30 to 100 ohms). One sees little change in the output power for the solid state ballast as compared to a large change for the conventional ballast for a given change in R_L load impendance. If the impendance load line were extended for the conventional ballast it would drop similar to that shown in Figure 4-7. One interesting point with the solid state ballast, which is not yet clearly understood, is the natural tendency to operate the lamp at a lower terminal voltage than with the conventional ballast. It is thought that this is due to the fact that the lamp acts as a pure resistance at the higher frequencies whereas the lamp when driven at 120 HZ turns on and off at this rate which causes the effective lamp impedance to vary. It should be noted that the Luminoptics design utilizes a non-modulated 27 KHZ sine wave drive. While the difference mechanism is not completely understood at this time it is thought that the distorted wave drive of the conventional ballast contributes to this "effective impedance"voltage difference and may also be behind the higher lamp terminal voltage phenomenon.

This observation suggests that it may be necessary to redefine the lamp trapazoid (tolerence limits) for undistorted high frequency operation. The implications are that lamp life may be extended when operated at high frequency.

In reviewing the ITL report of the solid state ballast, page 11, Appendix A, it would appear that the lamp impedance range is slightly limited with regard to the upper limits of lamp impedance. There is no technical reason why the impedance range of the solid state ballast cannot be designed to operate within the extended range (150 ohms or more) should this prove necessary. Part of the Phase II work for this contract involves further investigations in this area and corrections to the design if necessary and important.

Light output of a high pressure sodium (HPS) lamp is a function of lamp arc watts less lumen depreciation. Figure 4.5 depicts the variation in lamp arc watts as a function of lamp aging.

The manufacturers rated lumens from a lamp is achieved only when arc watts matches the lamp rated watts. In the case of the 200 watt HPS lamp, 22,000 initial lumens are delivered at this input power level. The reader should note that the conventional ballast, due to the variations in lamp load impedance, delivers 200 lamp arc watts at only two points during the life of the lamp; at the beginning of lamp life and at the end of lamp life.

By comparison, the solid state ballast delivers virtually 200 lamp watts throughout lamp life and therefore results in a constant lumen output.

4.3.2 Lumen Output Vs Input Voltage; Figure 4-6 describes lumen output at rated input voltage. Figure 4-6 shows, for the core coil system, that there is almost a $\pm$ 12% change in output power for a $\pm$ 10% change in line input voltage. There is relatively no change for the same lamp operated by the solid state ballast. Much smaller variations in light output are obtained when interchanging lamps of various manufacturers with the solid state ballast with a maximum of 4% in light output and only .8 of 1% in power input (See Figure 5-6, Section V).

4.3.3 Stroboscopic Effect; This effect is due to the cyclic variation of light emitted from a lamp and its rate is twice the line frequency with a conventional ballast. This cycling of light output can be either visually noticeable or subliminal. With high pressure sodium discharge sources high flicker indexes are present which prevent their use around rotating machinery unless special measures are taken with conventional ballasts to reduce the percent flicker.

Subliminal flicker is not noticeable by the eye. It is thought that the optic nerve responds to individual pulses of light but are apparently integrated by the brain so that the light source appears as a steady light. The effects of this type of stroboscophic flicker are sometimes blamed for eye fatigue and strain. The physological effects of subliminal flicker was not investigated during this contract.

The type of flicker that is of immediate interest is that which produces stroboscopic effect which makes rotating machinery appear to be stationary. Flicker effect is expressed as "flicker index or percent flicker." The exact definition of flicker index and percent flicker can be found in the IES Handbook, Fifth Edition, page 8-40.

The conventional single phase ballast was found to have a relatively high flicker index and percent flicker as compared to the solid state ballast with a non-modulated sine wave drive signal. Whereas the lamps operated with conventional 60 HZ ballast had a .2 flicker index and an 85% flicker content, the solid state ballast operating lamps at high frequency had a negligible flicker index of .015 and less than 3.5% flicker content. See Figure 4.9 for a summary of flicker tests conducted with both the standard and the solid state ballast.

4.3.4 Ballast Input and Output Waveshape; Figure 4-8 shows the input and output waveshapes for both the 60 HZ conventional and the solid state high frequency ballast. Waveshapes were also recorded by ITL and shown in Appendix A.

Figure 4-8A and 4-8C shows input voltage and the input current waveforms for the conventional ballast and the solid state ballast, respectively. On the input side to the solid state ballast the reader should note the current notching at zero crossover. This is caused by the power factor correction circuitry in the solid state ballast and is not considered significant nor is the slightly distorted voltage waveform of any importance for these tests because of the relatively high impedance power source used for the laboratory measurements. On the output side, the solid state ballast presents a near sine wave voltage and current to the lamp which improves ballast efficiency, lamp efficacy, and minimizes radiated EMI when compared to the peaked square wave drive of the conventional ballast. The oscilloscope sync was adjusted to show three complete cycles in each picture although the solid state ballast is operating at a much higher frequency. It should also be noted that the current crest factor for the solid state ballast is 1.5 or less which should improve lamp life.

4.3.5 Comparison of System Efficiency; From Figures 4-5 and 4-6 one can determine the relative system efficiency of the conventional and solid state ballast over line voltage variations at one point in the lamps life and also over the expected life of the lamp. One should note from Figure 4-6, that the solid state ballast always provides a gain in efficiency relative to the core coil ballast regardless of the variation in line input voltage (greater relative lumens for a given wattage imput). It should also be noted that because the solid state ballast is a regulated device in which the output power is not effected by changes in line voltage fluxuations; it will generate a more constant light output. The reader should also be aware that when high pressure sodium lamps are dimmed below a certain value of arc watts (about 75% of rated) there is a shift in spectral output toward the low pressure sodium color which gives a poor color rendering index. For this reason solid state ballasts have limited dimming range with the HPS lamp, although it is technically feasible to dim the lamp to under 10 arc watts.

Figure 4-7 also shows the power consumption of the conventional system and the solid state ballast over the expected life of the lamp. The life of the lamp is approximately 24,000 hours and is reflected by a change in lamp voltage from about 80 volts to 150 volts (RMS). As noted in 4.3.1, the solid state high frequency ballast tends to operate the lamp at lower voltages than does the conventional ballast for reasons which are not yet entirely clear. This may require a change in the lamp trapazoid for high frequency operation. Alternatively the lamp life might be extended for high frequency operation as there are no inherent technical reasons limiting the solid state ballast from operating the lamp beyond the present voltage limits of the trapazoid. The usual constraints are that end of HPS lamp life is where the ballast will no longer start and/or operate the lamp or where the color shifts due to a loss of sodium with lamp aging and the attendant drop off in lamp efficacy. Typically, cycling occurs since the lamp voltage to maintain the discharge is greater than can be supplied by the conventional ballast.

From the foregoing, it can be concluded the there are two major areas where the solid state high frequency ballast provides an increase in operating efficiency. The first is an increase in both ballast efficiency and lamp efficacy. The second is in operational savings due to the constant arc watts over the life of the lamp in which there is no need to provide excess illumination.

It should be noted that there was a difference in measured ballast efficiency for both the solid state and core ballasts when measured by ITL and Luminoptics Corporation. ITL reported a conventional ballast efficiency of only 77% vs almost 84% and they measured the efficiency of the solid state ballast at 93-97% vs only 88-90%. We feel that the differences between the independent laboratory measurements and our own are caused by differing test set ups and equipment for measuring high frequency power. Further testing by LBL is planned in the immediate future to sort out the differences to try to arrive at a common series of performance numbers.

The basic system efficiency gain is somewhere between 5 and 18% owing directly to improved ballast efficiency. On the subject of lamp efficacy, in-house tests were inconclusive for a variety of reasons mainly due to the methods of measuring lumen output under stable and repeatable conditions. We found that the improvement due to high frequency power to be between 0 and 8%. The eight percent improvement has been demonstrated before using higher wattage lamps (see High Intensity Discharge Lamps on High Frequency by John Campbell, General Electric Company, IES Transactions August 1969) however it is our feeling that this improvement is not acheiveable with the lower wattage sodium lamps and that, at most, approximately half that amount can be attributed to the high frequency operation. Further testing of lamp efficacy vs high frequency operation is underway at LBL and more conclusive results should be available in the not too distant future.

The greatest gain in efficiency, from a practical point of view, comes from the operational savings attributed to lamp aging. From Figure 4-5 one can readily determine that, provided the lamp ages at a linear rate, the difference between the total watts drawn by the conventional ballast and the solid state ballast is approximately 20% over the life of the lamp which is assumed to be 24,000 hours.

We suspect, and this is confirmed by at least one major lamp manufacturer, that that lamp ages at a non-linear rate and that the lamp stays in the area of high differential power draw for longer periods with overall savings approaching 40%. This will be confirmed by further testing whereby total power over the life of the lamp will be measured under field operating conditions.

LUMINOPTICS CORPORATION

ELECTRONIC HIGH FREQUENCY HIGH PRESSURE SODIUM LAMP BALLAST MODEL NUMBER 8661-01

SPECIFICATIONS

Light Output — The **Luminoptics** ballast shall operate with all commercially available lamps, either standard output or color corrected. For the purpose of comparing lamp lumen output, the **Luminoptics** ballast shall cause the lamp to output at least as many lumens as compared with a conventional magnetic coil and core ballast with 220 watts or less input to the ballast with 200 watts lamps and 240 watts for 250 watt lamps.

Power Input — The ballast shall operate from a standard line voltage of 277 Volts AC 60 HZ. The ballast shall be capable of maintaining rated lumen output over a 90-110% variation in the input main voltage within $\pm$ 3%. The ballast shall have a fused input.

Environment — The **Luminoptics** ballast shall operate at .9 power factor of higher (leading) at full output. The ballast shall implant no appreciable third harmonic distortion on the input power lines (current cresting which is defined as a maximum of 1.2 times the normal input current when measured against a comparable incandescent load). The ballast shall operate over a temperature range of 20-60° C. The ballast shall be inter-changeable with conventional coil core ballasts and will not adversely affect the power distribution system.

Spectral Composition — At rated lumen output, the ballast shall not cause any appreciable change in the color or spectral composition of the light emitted from the lamp. Note: during dimming operation there is a noticeable spectral shift toward one spectral line below approximately 75% of rated lamp watts.

Reliability — The **Luminoptics** ballast shall have a minimum rated life of 45,000 hours or ten years when installed and operated in accordance with the manufacturers recommendation.

Lamp Life — Lamp life shall not be reduced by virtue of operation from the Ballast.

Health & Safety — The ballast shall meet the functional intent of all recognized National codes including UL and ANSI as appropriate.

Emergency Lighting — The ballast shall be capable of operation from a standby battery source in the event of a failure in the main AC supply lines. Battery operation shall be a specified optional feature requiring a separate interface module. The battery may be included within the fixture itself. The length of time the ballast shall operate is totally dependent on the light level selected, battery capacity and battery type. A small battery may be utilized to maintain arc ignition during supply interruptions, so that as soon as main power is restored, the lamp will come to full brilliance in a very short time.

Level of Service (DIMMING) — The ballast shall have the capacity of being dimmed either manually or automatically through simple means. Local dimming is accomplished with a simple adjustment on the ballast proper. Remote dimming shall be accomplished via a pair of low voltage wires connected to a simple potentiometer emanating from the photo-cell control module. For U.L. specified operation, an isolator module in the fixture is required. "Level of Service" dimming shall be accomplished with the proportional photocell module located appropriately. All external control signals shall be low voltage (under 36 Volts) two wire control. Dimming shall be over a 75-100% range and shall be smooth in operation with no noticeable flicker or other objectionable effects.

Size — The ballast shall be mounted in a metal housing with mounting holes and wire color code identical to conventional ballasts. Where special wires are brought out (dimming, battery operation, etc.) they shall be color coded differently than other wires brought from the unit.

For complete specifications write to:
LUMINOPTICS CORPORATION • 12907 "H" ALCOSTA BLVD., SAN RAMON, CA 94583

LUMINOPTICS CORPORATION

SUMMARY OF KEY TECHNICAL CHARACTERISTICS
MODEL 8661
ELECTRONIC HIGH FREQUENCY
HIGH PRESSURE SODIUM LAMP
BALLAST FOR USE WITH
STANDARD 250 OR 200 WATT LAMPS
(EITHER HIGH OUTPUT OR COLOR CORRECTED)

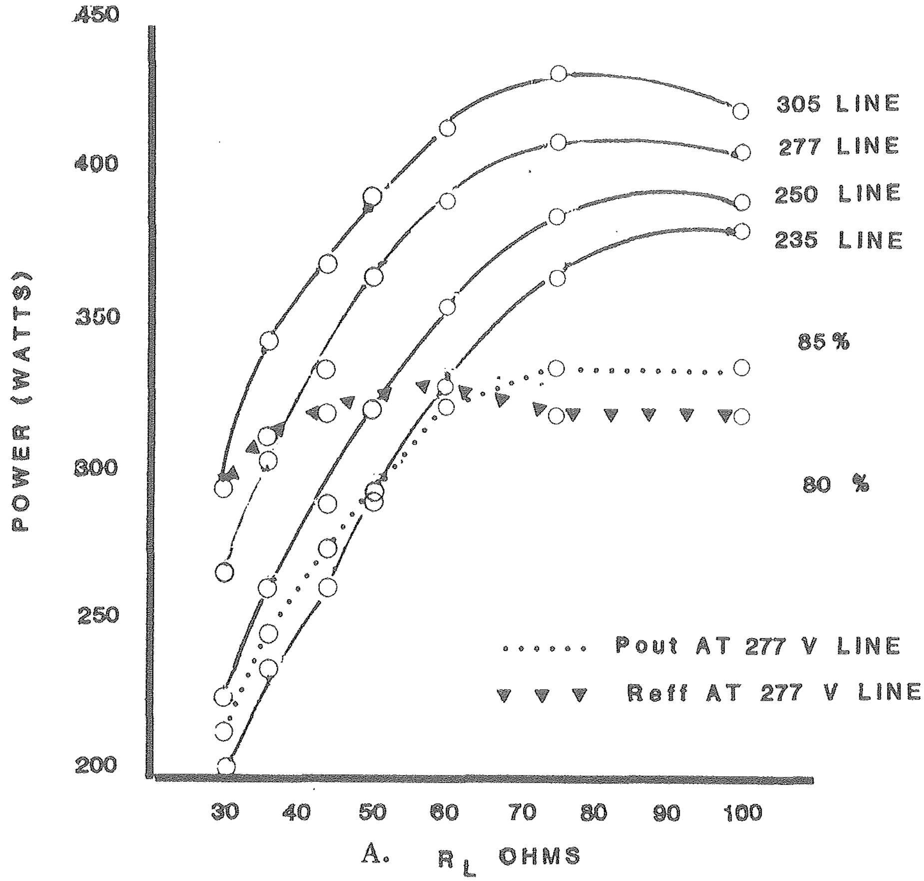
INPUT	AC Input Voltage	235-305 Volts, AC, 60 Hz. (277 Volts Nominal)
	Minimum Starting Voltage	235 Volts AC
	Maximum RMS Operating Current at ,000 Lumens	1.0 Amps.
	Maximum Starting Current	1.1 Amps.
	Power Factor	.95 Leading (Typical) at full light output
	Third Harmonic Distortion	Negligible
OUTPUT	Lamp Drive Frequency	27 KHZ $\pm$ 1 KHZ
	Lamp Operating Voltage Range	75-150 Volts (determined by lamp characteristics)
	Open Circuit Voltage	*
	Lamp Lumens	As rated by Lamp Manufacturer
	Lamp Crest Factor	1.48 $\pm$ 10%
	Dimming Range	75-100%
	Flicker Index	Zero
	Percent Flicker	Zero
	EMI	Projected to meet FCC Part 15
	Lamp Type	Any Standard Commercially available type.
PHYSICAL	Ballast Weight	2.2 pounds (1 Kilogram)
	Ballast Size	4.0"H x 4.25"W x 6.625"L ($\pm$ .010) Mounting holes are same as most transformer ballasts. Ballast is complete including ignitor.

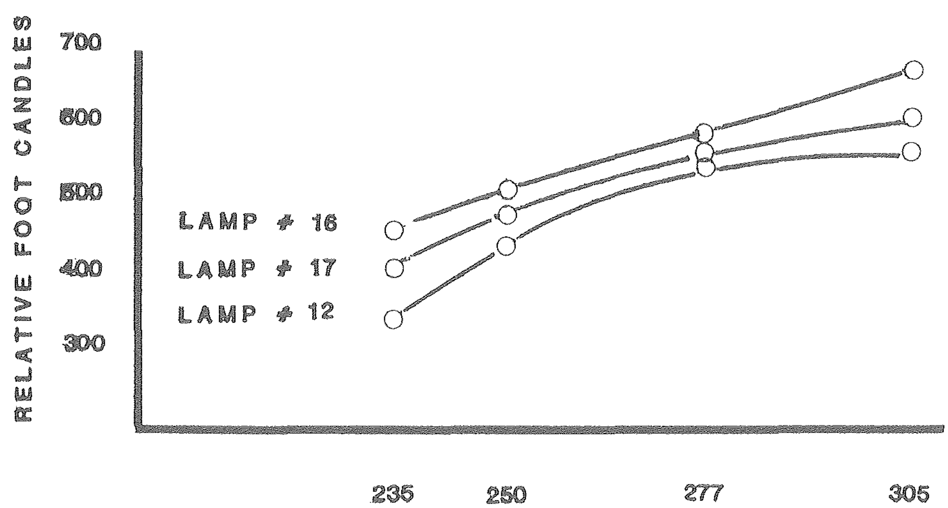
*Contains built in ignitor. Initial lamp ignition is by 4000 volt (maximum) pulse 1 usec wide at 10 HZ rate. Nominal open circuit RMS voltage is 215 Volts.

For complete specifications write to:
LUMINOPTICS CORPORATION • 12907 "H" ALCOSTA BLVD., SAN RAMON, CA 94583

FIGURE 4-3

CONVENTIONAL BALLAST 200 WATT HPS LAMP

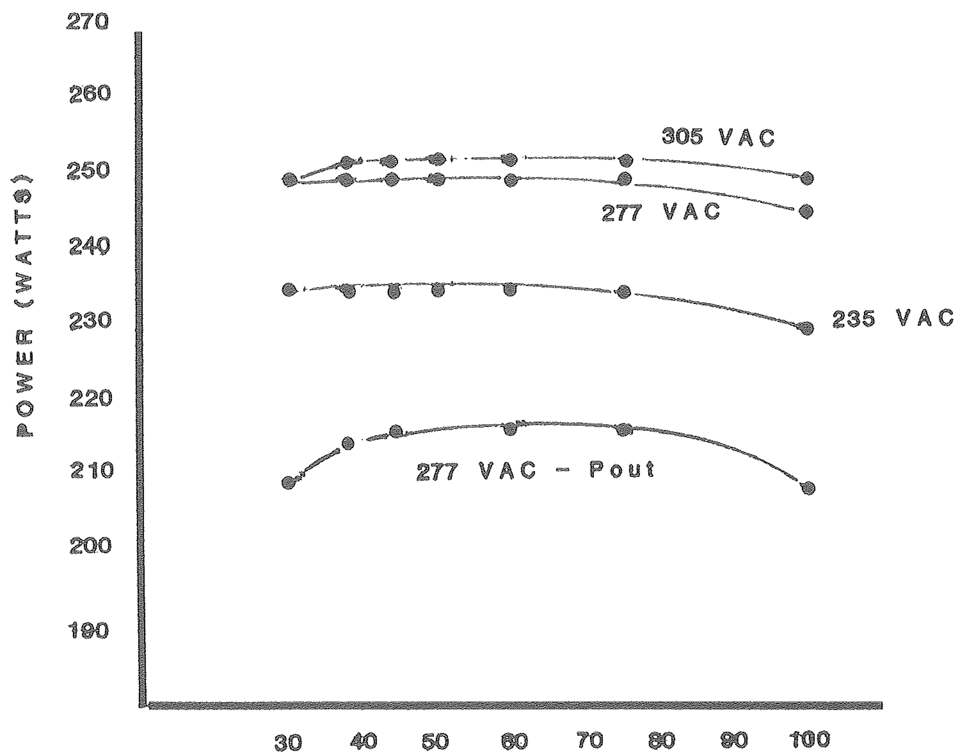




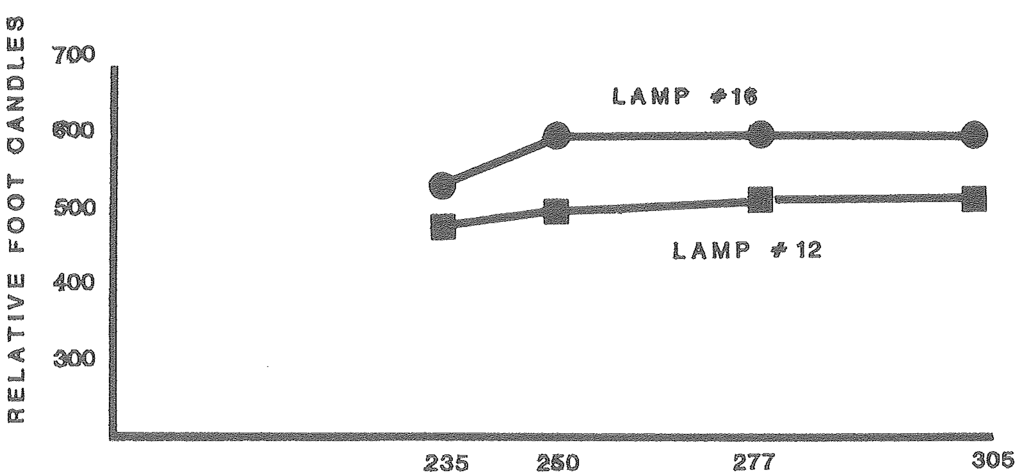
EFFECTS OF CHANGES IN LINE VOLTAGE AND LAMP IMPENDANCE ON CONVENTIONAL BALLAST SYSTEM

FIGURE 4-4

LUMINOPTICS BALLAST MODEL 8661-01 200 WATT HPS



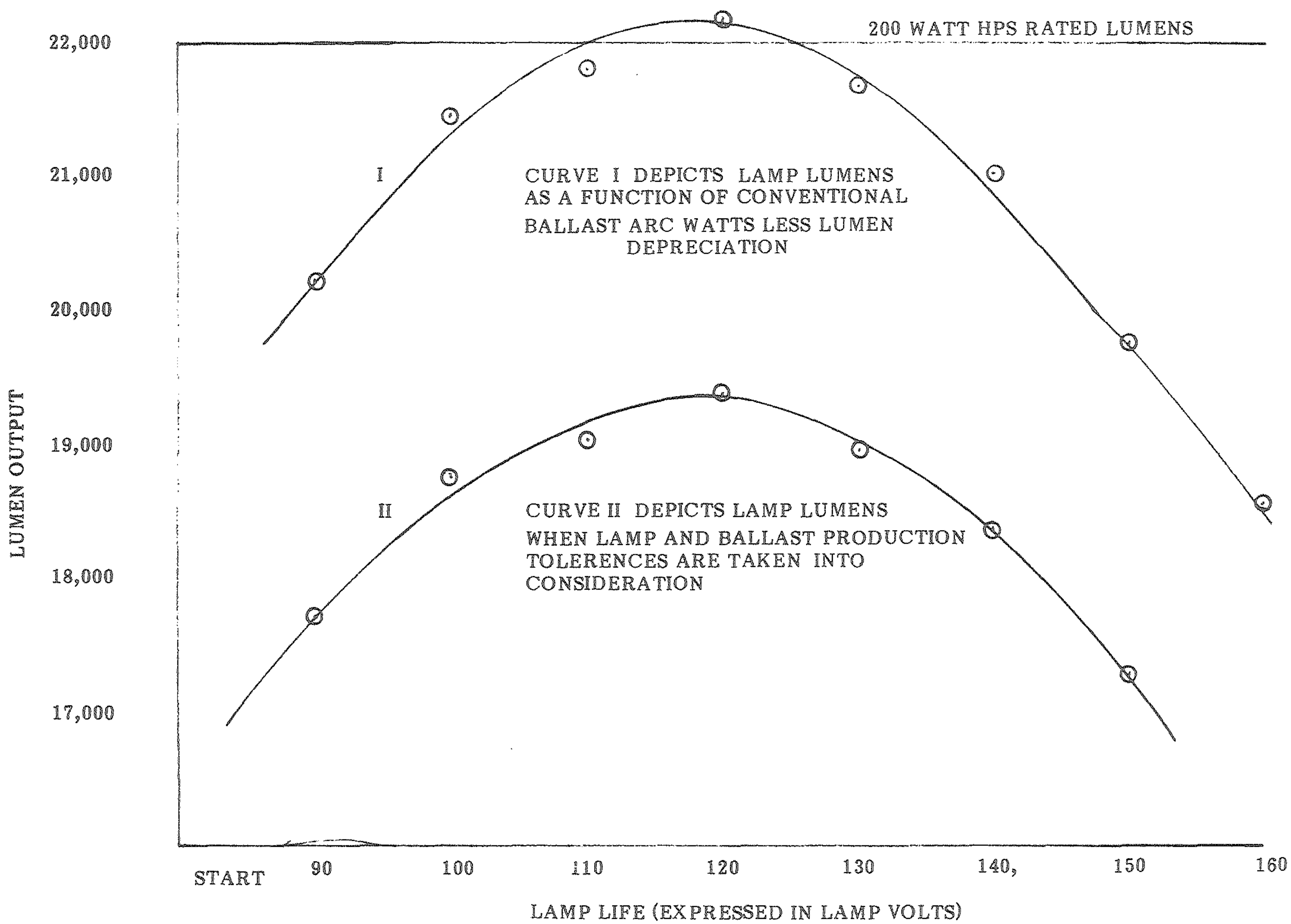
A. R_L OHMS



B. LINE VOLTAGE

EFFECTS OF LINE VOLTAGE VARIATIONS AND CHANGES IN LAMP IMPENDANCE ON SOLID STATE BALLAST

FIGURE 4-5



LAMP LUMENS SHOWING COMBINED EFFECT OF LUMEN DEPRECIATION, UNREGULATED ARC WATTS, AND LAMP AND BALLAST PRODUCTION TOLERENCES.

..../16

FIGURE 4-6

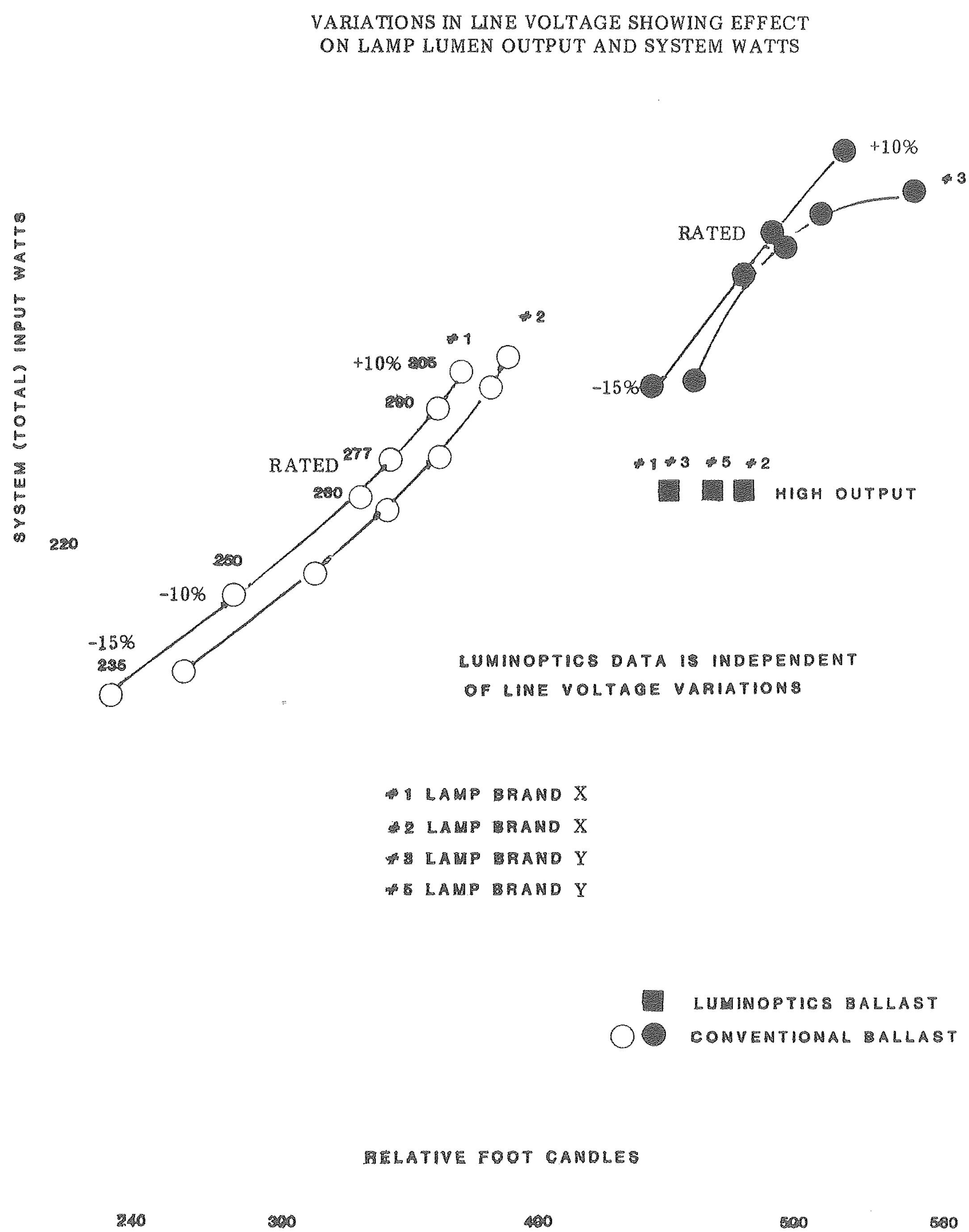
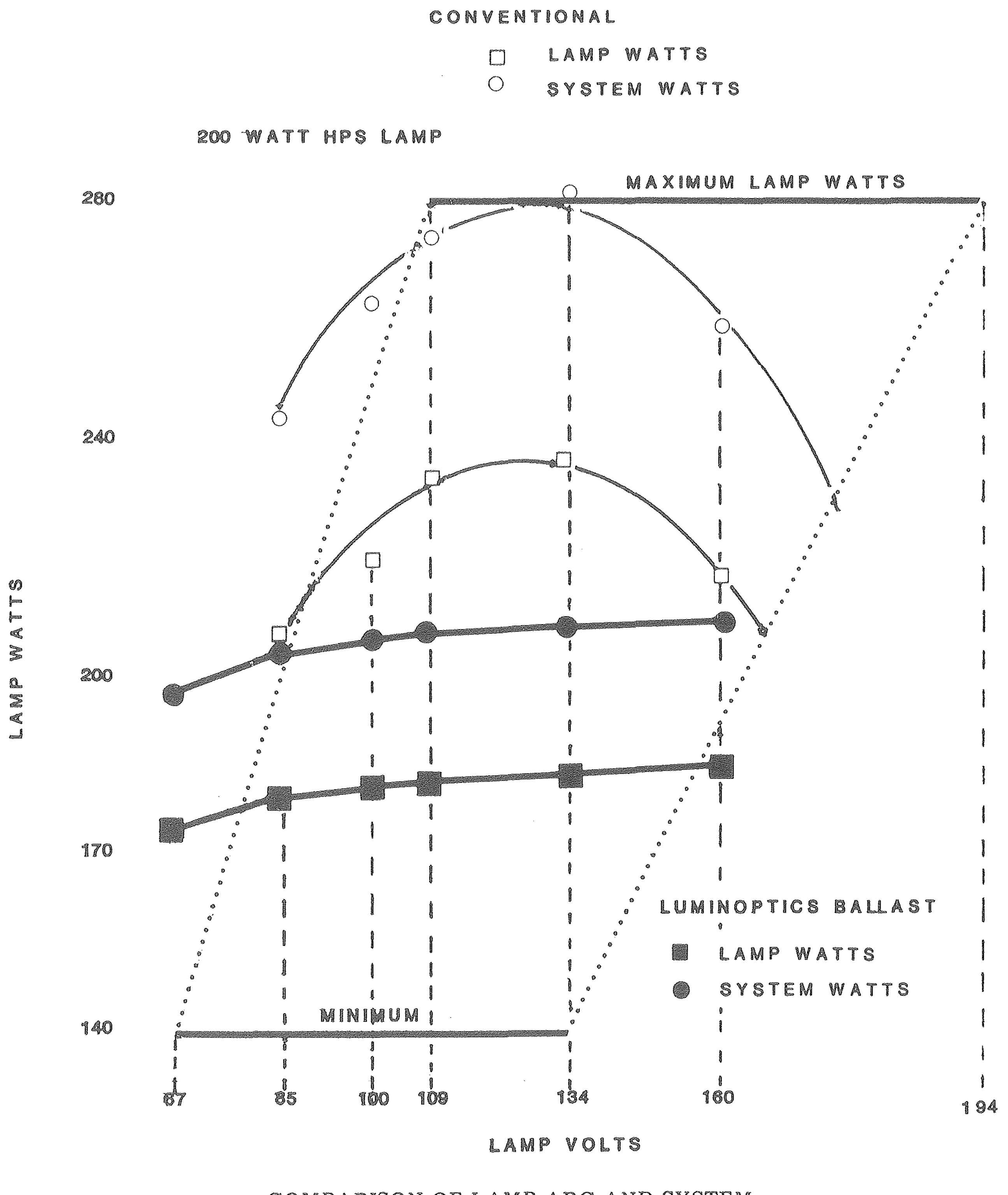

VARIATIONS IN LINE VOLTAGE SHOWING EFFECT
ON LAMP LUMEN OUTPUT AND SYSTEM WATTS
SYSTEM (TOTAL) INPUT WATTS
+10%
#3
RATED
#2
#1
+10% 305
290
-15%
RATED 277
260
#1 #3 #5 #2
HIGH OUTPUT
220
250
-10%
-15%
235
LUMINOPTICS DATA IS INDEPENDENT
OF LINE VOLTAGE VARIATIONS
#1 LAMP BRAND X
#2 LAMP BRAND X
#3 LAMP BRAND Y
#5 LAMP BRAND Y
LUMINOPTICS BALLAST
CONVENTIONAL BALLAST
RELATIVE FOOT CANDLES
240
300
400
500
560

FIGURE 4-7



COMPARISON OF LAMP ARC AND SYSTEM WATTS. CONVENTIONAL VS SOLID STATE BALLAST.

Figure 4-8

Ballast Current-Voltage Wave Shapes

Core-Coil

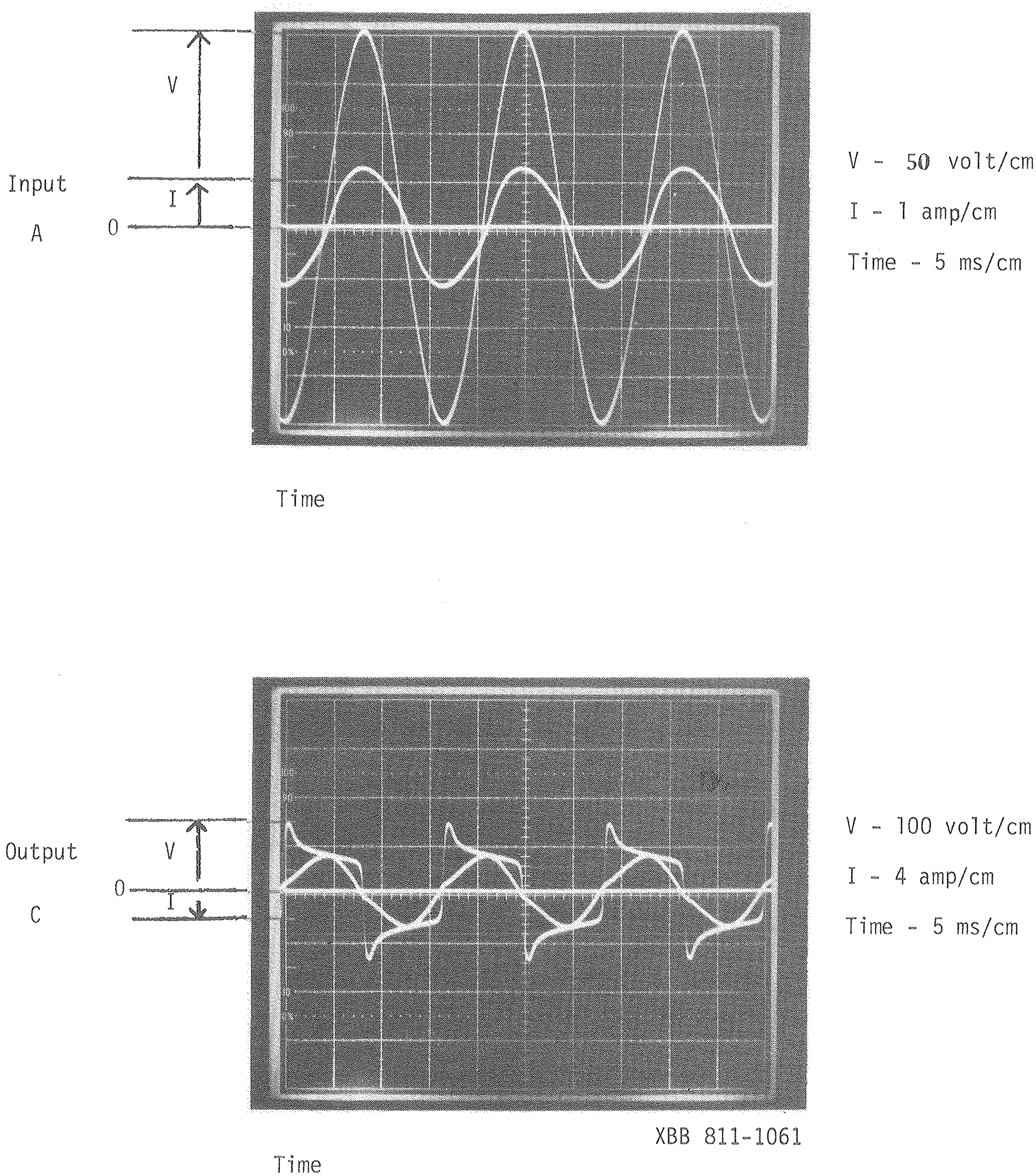


Figure 4-8 Continued

Ballast Current-Voltage Wave Shapes

Solid State

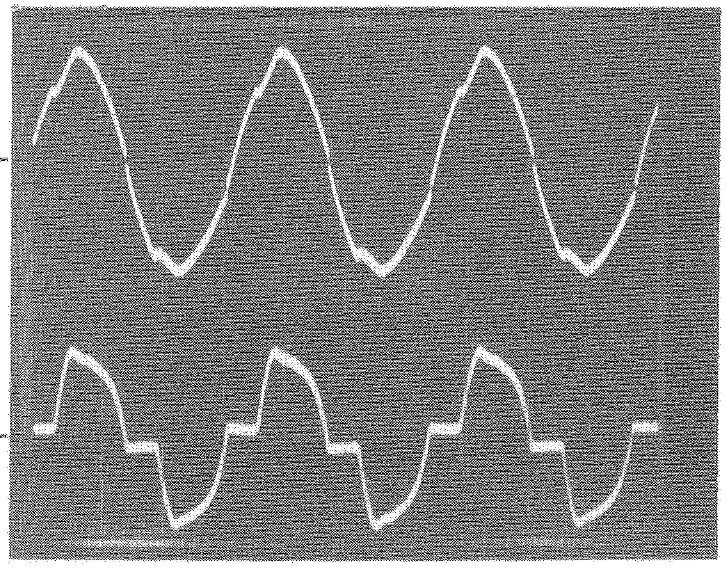
Input B

V

0

I

0



V - 200 volt/cm

I - 1 amp/cm

Time - 5 ms/cm

Time

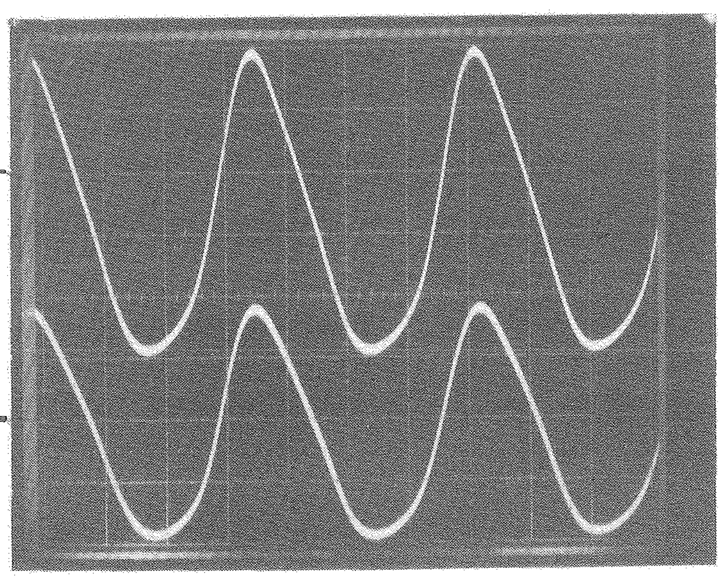
Output D

V

0

I

0



V - 50 volt/cm

I - 2 amp/cm

Time - 10 ms/cm

XBB 811-1062

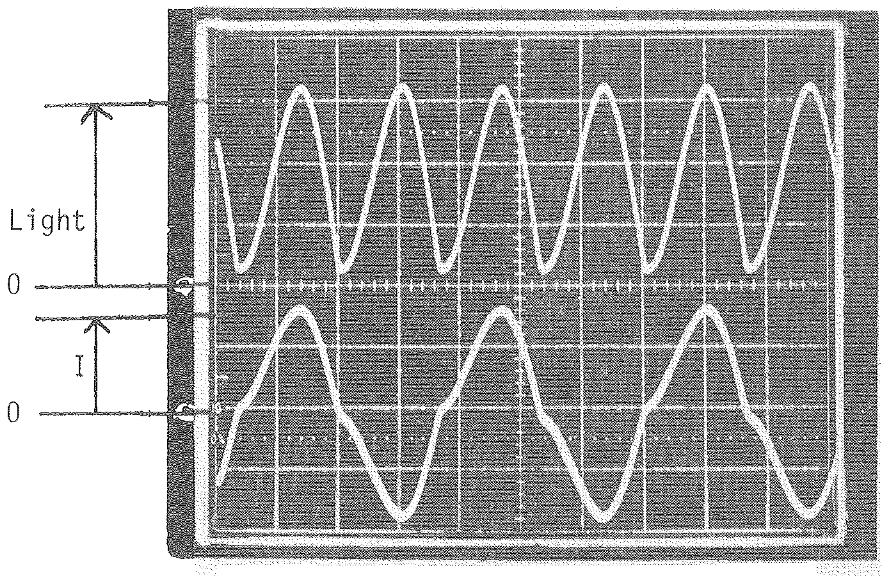
Time

Figure 4-9

Light Flicker for HPS Lamp

With Core-Coil and Solid State Ballasts

Core-Coil



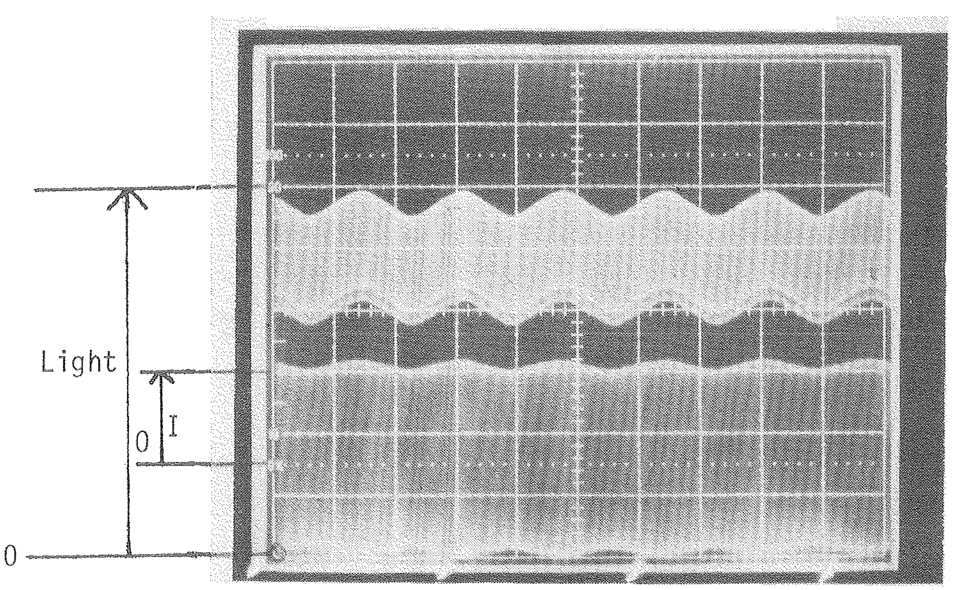
Light Output - Arbitrary

Lamp Current I - 2 amp/cm

Time - 5 ms/cm

Time

Solid State



Light Output - Arbitrary

Lamp Current I - 2 amp/cm

Time - 5 ms/cm

XBB 811-1063

Time

5.0 TASK III - ENERGY LOSS ANALYSIS

5.1 TASK STATEMENT

A. Identify and compare power/energy losses, (compare core-coil with solid state).

1. Ballast
2. Lamp
3. System

B. Identify and describe power/energy operational losses, (compare core-coil and solid state).

C. Considering IIIA and B above, determine both the annual cost savings of the product and the life cycle cost savings. Specify condition of the calculations.

5.2 Conventional Ballast/Lamp System; In order to properly understand the HPS lamp system it is important to understand the conventional system as it now operates and where it's losses occur. From Figure 5-1 the conventional core-coil system is composed of a ballast, a starter and a lamp. The lamp is a two hundred (200) watt high pressure sodium lamp (HPS) that is manufactured by major lamp manufacturers in the United States for use with an ANSI Standard S-66 ballast. The lamp operates with a nominal 100 volt operating characteristic and the ballast used in these tests is a commercially available auto regulated type with power factor correcting capacitor with an electronic starting circuit external to the ballast.

The HPS lamp is a very efficient source of illumination when compared with other HID lamps. It is capable of generating 22,000 initial lumens (19,800 lumens at 50% life). The lamp consists of a mogul base, a ceramic arc tube, and two coated tungsten electrodes. The lamp is filled with various gasses including mercury and sodium. The assembly is attached to the base and is enclosed in an evacuated glass envelope.

The ballast that controls the lamp is connected to a 60 HZ source of power (the main AC supply). The function of the ballast is to raise the line voltage, in this example 277 VAC (RMS), to a sufficient level via the electronic starting circuitry, to initiate ionization of the gas within the lamp and then, when the lamp begins conduction, to limit the amount of electrical current flowing through the lamp.

The 200 watt HPS lamp was chosen for this project because it was a logical replacement for a 400 watt mercury vapor lamp which emits between 18,000 and 19,000 initial lumens and is in widespread use in outdoor street lighting. The 277 VAC input voltage was chosen because it is the dominant supply for indoor commercial and industrial lighting and because it is one of the most difficult to do electronically and represents the most advanced state-of-the-art design.

High pressure sodium lamps require a short duration starting pulse of between 2,500 and 4,000 volts peak to peak amplitude to initiate ironization of the lamp. The conventional ballast has an efficiency rating of between 77 and 84% which means that between 33 and 26% of the energy consumed by the ballast lamp combination is used by the ballast. The HPS lamp has a high efficacy (about 110 lumens per watt), however, when one takes the ballast losses into consideration the system efficiency drops to about 82 lumens per watt or about the same as a good fluorescent ballast/lamp system. The HPS lamp has a relatively poor color rendering index and a high stroboscophic effect due to the the operation of the lamp at 60 HZ

5.3 Comparing Ballast/Lamp Systems Losses; the factors that must be taken into consideration when comparing energy and power losses for either the conventional system or the solid state system can be categorized as basic losses and operational losses. For comparison purposes the conventional ballast becomes the standard from which all measurements and evaluations are made in terms of the ballasts ability to generate light and the operational losses take into account the varing nature of the lamp when used over it's natural life and their effect on system efficiency. Six factors must be taken into consideration when discussing these losses. They are:

1. Lamp Efficacy
2. Ballast efficiency: P^{out}/P^{input}
3. Lumen depreciation
4. Input line voltage - lamp watts regulation
5. Arc watts as a function of lamp aging and effect on lumen output
6. Power factor and third harmonic distortion

5.3.1 Lamp Efficacy; This is a "figure of merit" used to describe the efficiency of the lamp in terms of converting electrical power to visible light and can be likened to a miles per gallon comparison for an automobile. The lamp efficacy is derived by dividing the lumen output by the input power to the lamp. The units of efficacy are expressed in lumens per watt (LPW).

The two hundred watt lamps utilized in this test have an efficacy rating of 110 lumens per watt when measured intially or 99 LPW when the measurement is made at 50% rated life. From page 8 of the ITL report, Appendix A, the figure of merit for the lamp tested was 106.5 LPW for the 60 HZ core-coil ballast and 117.4 LPW (page 5) for the solid state ballast. This increase of 10.9 LPW or 9.2% is attributable to the use of high frequency and provides evidence to support prior results found at the General Electric Company and reported in the Transactions of the IES, December 1969, by J.H. Campbell.

It is necessary to note here that internal testing by Luminoptics Corporation was inconclusive in this area. We did in fact see improvements in lamp efficacy, however, the figure varied from 0 to 8%. We believe that our inability to consistentently measure improvements in lamp efficacy were in part dependent on our particular laboratory setup and instrumentation, the relatively small population of lamps tested, and the simple light measuring techniques that were employed.

The exact reasons for the increase in lamp efficacy was not investigated during this contract nor was it intended to do so. It is thought that the increases are due to better power transfer characteristics at the higher frequencies and also to the higher energy density within the arc itself. Unfortunately this phenomenon varies with lamp drive waveshape, current crest, and other factors as well as frequency and would take considerable resources and time to define the effect on efficiacy as a function of so many variables. It suffices for now to acknowledge the effect and take advantage of it's benefits.

One interesting aspect was noted during the testing of one manufacturers lamps. When the arc power levels were raised well above the lamp rated arc watts the high frequency arc was noted to wander within the ceramic envelope which caused a shift in the lamps focal plane and resulted in a low frequency flicker being observed. This effect was duplicated on other lamps of the same manufacturer but could not be duplicated on lamps of the other manufacturer. In as much as the problem occurred only when the lamp was overdriven there was no attempt to define the nature of this phenomena. It is anticipated that during the second phase of the contract, some work will be dedicated in this area as a matter of scientific curiosity and reported on at the appropriate time.

<u>5.3.2 Ballast Efficiency</u>; Ballast efficiency is determined by measuring the total power out of the ballast and then dividing that by the total power into the ballast. For the 60 HZ ballast it is a rather simple and straightforward matter as one can easily measure the 60 HZ power. The conventional ballast efficiency is typically 65 to 85% with new lamps.

In its operating environment the ballast must tolerate wide shifts in lamp characteristics (arc impendance) as the lamp ages. The major characteristic indicative of lamp aging (with the conventional ballasts) is an upward shift in lamp voltage. While the manufacturer rates the lamp with a nominal 100 V (RMS) characteristic; the lamp will shift it's operating voltage, with time, over a range from about 67 V(RMS) to as much as 180 V (RMS).

When testing ballasts for efficiency the methods of measurements and the type of test equipment chosen to perform the tests are important. When measuring high frequency power the test equipment must respond at the higher frequencies. The measurement techniques and circuitry also become vital when measuring ballast efficiency and power losses as the lamp ages. Accepted industry practice is to simulate aged lamps by externally heating the lamps.

Another way of assessing the ballast performance is to use a non-inductive resistor to simulate the arc impedance of the lamp.

The arc impendance of a particular size lamp can be readily estimated. In the case of the 200 watt HPS lamp, the measured impedance is 30, 80 and 100+ ohms at the beginning, middle and end of lamp life respectively. This correcponds to a voltage range from 67 to approximately 140 volts.

Figure 4.3 and 4.4 shows the output power over the operating voltage range of the conventional ballast and the solid state ballast. The efficiency of the core-coil ballast tested varied between 80 and 83 % over the range compared with a 88% efficiency for the solid state ballast which was virtually unchanged for all load impendances. It should be noted that the independent laboratory tested the conventional ballast (Appendix A) at 77% compared with 95% for the solid state unit. The conventional ballast was also tested by LBL at 77% which indicates that there are measurement discrepancies between the various facilities running tests. Further testing is planned by the Company and will be reported during the next phase of the contract.

The conventional ballast effeciency/power losses at various values of load impendance (R_L) can be summarized as follows:

LOSS ELEMENT	R_L 30 OHMS	R_L 80 OHMS	R_L 100 OHMS
Ballast Efficiency	80.0%	82.5%	82.5%
Power Losses	48 Watts	46 Watts	46 Watts

5.3.3 Solid State Ballast Efficiency; The solid state ballast consists of a self contained starter, power factor correcting circuitry, logic supply and control circuitry, and a lamp driver section. The ballast has similar physical diminsions as the conventional ballast system it replaces.

Figure 5.2 is a very simplified block diagram of the solid state ballast. The ballast converts the line input (AC) power to a direct current (DC) and then inverts the DC power to a high frequency drive signal to the lamp. In addition a + 24 VDC power supply is utilized to supply logic power to both the power conversion circuits.

The power loss analysis of the 200 watt HPS solid state ballast can be divided into two sections. First the losses associated with converting the AC input to DC; and, second the losses allocated to inverting the DC power to a high frequency drive signal to the lamp. The losses connected with miscellaneous circuitry such as the + 24 Volt logic supply are included in either the AC to DC converter or lamp driver as appropriate.

5.3.4 AC to DC Conversion Losses; Included in this section are the input filter, transient protection circuitry, bridge rectifier and switch mode power supply and power factor correction circuitry. The purpose of this section is to convert the 277 Volt AC line input to + 175 VDC and to do so at near unity power factor with little or no third harmonic distortion and with a minimum of EMI. This power supply section is commonly called the down converter.

The efficiency measured on several of the +175 Volt Down Converters shows them to be consistent in performance in terms of operating over the entire range of input voltage (± 10%). The Down Converter losses can be characterized as follows:

Input Voltage, RMS	277.0
Input Current, RMS	.8
Input Power, Watts	213.0
Power Factor 213/224.5	94.9%
Output Voltage (VDC)	172.2
Load Resistance in Ohms (R_L)	147.3
Output power (Watts) to load	201.5
Power Loss (213-201.5)	11.5
Uncertainty ± 2% of 200 watts	± 4.0
Efficiency, (P_{out}/P_{in} X 100)	94.6%

Major first order power losses within the Down Converter are as follows (expressed in watts):

+ 24 Volt logic Supply Voltage	2.26
Input bridge rectifier & line filter	1.31
Switching transistor losses	2.03
Switching inductor losses	1.65

Power diode losses	2.05
Main Switching transistor protection	4.22
Total losses	13.52

5.3.5 Lamp Inverter or Driver; Included in this section is all the circuitry necessary to control and drive the lamp including the oscillator, lamp control, dim control, and sine wave drive supply. First order losses include:

+ 24 Logic Supply Voltage	3.20
Switching Transisor Losses	4.45
RFC Choke	2.92
Other Inductors	6.49
Power Diode	.79
Misc. Components	.23
Total losses	18.08

5.3.6 Total Solid State Ballast Losses; When both the Down Converter losses and the Lamp Driver losses are added up and compared to the total system power input, the calculated efficiency of the solid state ballast is 88-90%, which is a significant improvement compared with between 75-84% for the conventional ballast.

5.3.7 Lumen Depreciation; This term is used to define the decrease in light output as a function of lamp aging and is usually expressed as a percent in fall off from the initial lumen rating of a given lamp to its lumen output at end of useful light. In the case of the 200 watt HPS lamp, lumen depreciation is about 20%.

The controllable solid state ballast offers some significant advantages over the conventional ballast. Because the lamp watts can be precisely controlled, and therefore the lumen output, a fixture can be rated at one lumen output that will be maintained over the life of the lamp. This is accomplished by a positive feedback system which measures fixture light output or flux and automatically adjusts lamp arc watts to maintain the desired light output from the fixture.

This positive feedback system can also compensate for recoverable light loss factors such as, room surface dirt depreciation, lense aging, and dirt accumulation.

The expected power savings utilizing the lumen depreciation compensation circuitry employed by the solid state ballast is about one half the expected fall in lumen output due to the above factors assuming a linear relationship between lamp arc watts and lumen output.

One last parameter which effects lumen output is lamp current crest factor. As a general rule of thumb the higher the peak to RMS current ratio (the current crest factor) the greater the lumen depreciation. The solid state ballast drives the lamp with a current crest factor under 1.5 which should improve both the lumen depreciation and the lamp life.

5.3.8 Input Supply Line Variations; As shown in Figures 4.3A and 4.3B, ± 10% variations about the center design input voltage effects large changes in the lamp power and light output for conventional ballast/lamp system compared to a solid state ballast/lamp system. Figure 5.3 graphically illustrates this effect for a 150 watt HPS lamp on a reference ballast system when operated at 90, 100, and 110% of line input voltage.

The conventional ballast/lamp system was tested by Luminoptics Corporation, (Table 5.4), and it's ability to regulate lamp arc watts as a function of variations in line input voltage over a 90-110% (250 to 305 VAC) range was measured to be ± 9.3%.

The solid state ballast displayed a line regulation over the same ± 10% about design center voltage of ± 1.3% in power and less than ± 2% in light output variation with some units having displayed .3% wattage regulation and .3% light output regulation. In application this improved regulation characteristic of the high frequency system will reflect another 5% in direct power savings.

It should also be noted that ITL (Appendix A) measured a 22% variation in wattage and a 25% variation in lumen output from 90 to 110 % of line with the conventional ballast and a 3.2% variation in power and a 1.3% variation in light output for the solid state ballast. This data is an agreement with the Luminoptics testing.

5.3.9 Arc Watts as a Function of Lamp Aging; Lamp arc watts variation as a function of lamp aging is the dominant loss factor from an operational point of view. Figure 4.7 depicts both the lamp power consumption and the total system consumption over a range of 67 lamp volts to 194 lamp volts. When a lamp is new it operates at a lamp voltage at the left hand end of the lamp voltage scale and as the lamp accumulates operating hours it's characteristic impedance shifts in such as manner that the voltage needed to maintain the discharge increases.

The lamp manufacturer specifies that lamps must be operated within certain power and voltage ranges which are within the trapazoid shown in Figure 4.5. The upper and lower wattage limits of lamp operation are shown by the minimum and maximum (solid) lines. The minimum and maximum lines are determined by a percentage offset from the designed lamp watts (the nominal value) which in this case is 200 watts. Both the upper and lower limits are between 20 and 40% above and below the rated lamp wattage value. The maximum line is offset from the minimum line to reflect the lamps ability to handle current flow at various values of lamp wattage and the resultant, is a trapazoid which defines the limits of lamp operation. A trapazoid for each type and lamp wattage is published by ANSI and is used by the ballast manufacturers as the targets for the lamp when they design their product.

The design rules are that the ballast must operate the lamp, under all conditions, within the trapazoid. This is verified by measuring lamp watts produced by the ballast under 90 and 110% of line input voltage plotted against lamp volts (lamp aging). The lamp operating points must enter and leave the sides of the trapazoid and never intersect either the the maximum watts or minimum wattages.

The conventional core-coil ballast exhibits a humpback curve when traversing the trapazoid and it will operate the lamp above the specified lamp wattage. The uppermost line for both conventional and solid state ballasts represents total system input watts and is shown here only for reference. The effect of line voltage variations was not included in this graph in order to simplify the presentation, however, the lamp operating points normally consists of a series of three lines representing operation at 90, 100, and 110% of nominal input line voltage.

The solid state ballast is represented by the heavy solid lines in Figure 4.7. The upper curve represents total system watts and the lower lines represent lamp arc watts. The solid state ballast provides constant arc watts control whereby the electrical drive parameters of the ballast are automatically altered in response to changing lamp characteristics to achieve a constant level of arc watts throughout the life of the lamp. This is extremely important in that the difference in lamp arc watts for the lamp operated with the conventional ballast (humpback curve) and for the lamps operated with the solid state ballast the lamp arc watts represents a savings in energy to achieve the same level of work. In this particular case we have estimated the savings attributable soley to lamp aging to be at least 20% over the life of the lamp on the assumption that the lamp ages at a linear rate. Westinghouse Electric Company presented a paper at the IES National Technical Convention in Atlantic City, September 1979, indicates that the savings with constant arc control are higher at least 20%. The savings from operational use could be higher, perhaps as much as 40% under some conditions. The exact amount of power savings through constant arc watts control will be the subject of further study later in this program.

5.3.10 Power Factor and Third Harmonic Distortion; Power factor is a term used to describe the efficiency with which electrical devices draw power from the main AC supply lines. Third harmonic distortion refers to the input current peaking which appears as the third order line distortion of the fundemental frequency.

Power Factor - is the phase relationship between current and voltage as drawn by the device under test. Further, it is also the relationship between the apparent power drawn by the device and the true power. This is called "shape" power and is the general definition of power factor. Power factor is defined as:

$$\text{POWER FACTOR} = \frac{\text{TRUE POWER (Watts)}}{\text{APPARENT POWER (RMS Volts X RMS AMPS)}}$$

Power factor (PF) usually has significance for the end user only when it is below .85. When power factor drops too low some utility companies may charge an additional amount of money to the end user because they must either supply power factor correcting capacitors at the sub distribution points or absorb the additional I^2R losses within their distribution system. It is very difficult to quantify the specific savings to the customer for good power factor except to mention that the usual penalty (which varies significantly) is a surcharge of 1% for each one percent decrease in power factor below .85. There is however a cost to society for poor power factor connections within the utility system. The additional I^2R losses must be absorbed by the utility which also has to increase production to compensate for these losses. Increased production means more power plants, a higher rate base, greater dependence on relatively insecure foreign oil sources, and increased and needless additional risks with the natural environment.

Third Harmonic Distortion is a term that describes the input current peaking that is inherent in the design of most switching power supplies such as the solid state ballast. The technical description of the exact term can be found in Document 34C (Secretariat) 96 of the International Electrotechnical Commission. As a general rule third harmonic distortion requirements are not specified in this country and only become a problem when very large numbers of electronic equipment are installed in any dedicated distribution system. The problem, when it occurs, shows up as large neutral currents, and drastically increased I^2R losses in the distribution system.

With the advent of the solid state ballast, with it's significant energy savings potential through gains in efficiency, it is likely that ten of hundreds of thousands and perhaps millions of units will be installed in this country over the next ten or so years. When this occurs it will be important to specify, in some way, the third harmonic distortion limits of installed devices to prevent further I^2R losses within the distribution system and to insure that the use of many of these devices will not become a safety or fire hazard.

The solid state ballasts developed by Luminoptics Corporation operate with good power factor and with a minimum of third harmonic distortion due to the unique and proprietary nature of the Company's designs.

5.3.11 Other Factors; Other factors effecting ballast/lamp system losses include: temperature variations, lamp production tolerences, ballast production tolerences, and lamp to lamp and ballast to ballast variations.

Temperature testing conducted by the Company with the conventional ballast revealed that there can be as much as a 7½% variation in input wattage and a 6% change in light output, with changes in ballast temperature. With the solid state ballast the effects of temperature variations are very small, less than 2% because of the solid state ballast's constant output power with variations in the load. Figure 5.5 is a graph of the temperature tests.

Lamp and ballast production tolerences. As a general rule lamp production tolerences are held in the range of 5-10% range in terms of light output for rated arc watts. Ballast production tolerences are unknown, however, if the production tolerences for fluorescent ballasts are used for example, it is expected that HID ballast production tolerences are in the order of 7.5 to 12.5% in terms of light output with reference lamps. The solid state dimmable ballast has a significant advantage in that it can compensate for both lamp and ballast tolerences with it's natural ability to adjust the amount of lamp arc watts either manually or automatically.

A test was conducted to determine the variations in lamp performance for lamps from the same manufacturer. (effect of lumen output and power input). One high performance conventional ballast was used as a reference. Table 5.6 is the results of those tests where three lamps each from two manufacturers were run with the conventional ballast and then with the solid state ballast. With the conventional ballast a 14.8% variation in power consumption was noted resulting in a 19.7% variation in light output. When the same tests were run with the solid state ballast, a .8% variation in input wattage was noted with only a 3.8% variation in light output.

This is extremely significant in that the performance of a conventional HPS system may not be the same if a lamp, even if from the same manufacturer is replaced, as in the event of a lamp failure. The improved uniformity of lamp performance with solid state ballasts could reflect an energy savings of 20%.

5.4 Summary and Comparison of Loss Factors; The power/energy loss factors are summarized below. Where possible we have attempted to fix variables to arrive at a single number and where this was not possible, a range of likely numbers has been included.

LOSS ELEMENT/IMPROVEMENT	SOLID STATE BALLAST	
	LOW	HIGH
Basic ballast efficiency	4	9 %
Lamp efficacy	4	8
Lamp aging (constant wattage)	20	40
Line voltage fluxuations	0	5
Lamp production tolerences	5	10
Ballast production tolerences	5	12
Lamp to lamp variations	0	20
Lumen depreciation	10	20
Other light loss factors	5	10

It should be clearly understood that all of the improvements listed above do not occur at the same time and that further testing is required in application to determine the exact savings in power for a given lumen output. However, based on an evaluation of all data it appears likely that the range of savings will fall between 34 and 45% depending on the application and the fixture. The Company plans to conduct further development work to achieve an average 45% power savings in operation in most fixtures with suitable guarantees to the end user.

In addition the solid state ballast has the capability to be dimmed over a range, limited only by the acceptable color change. This could be significant in terms of making each fixture a task lighting fixture. Where daylighting and/or task lighting control schemes are utilized a further 10-20 percent reduction of energy is possible. Company tests have indicated the HPS lamp can be dimmed to about 75% of the rated lamp watts without adverse color shift. Dimming below this level may not be recommended except for standby battery operation or where color balancing is available from other light sources.

5.5 Annual Cost Savings and Benefit Analysis; The initial ballasts manufactured under this contract are hand built units and therefore quite expensive. Cost projections based on these units would be meaningless, however, cost projections can be made based on expected development of the ballast design and their manufacture in quantity. For the purpose of these comparisons we have made several assumptions about the product which are defined below.

The product, in it's present form, can be cost reduced and built for about $32 each (labor and materials only) in a low cost labor area. A $32 labor and materials cost translates to a selling price in the existing distribution system of about $160.00 each. This compares with a retail price for similar conventional ballasts of about $150.00 in 1980 dollars. One must be extremely careful when comparing distribution costs. Present industry practice is to grossly inflate the suggested list price of lighting products and then give enormous discounts to the trade approaching 50 and 60% under some conditions. Ballasts are rarely sold at their suggested retail price and the discounts vary in accordance with various pricing policies developed by the distributors to meet their own requirements. This practice is in widespread use not only in the lighting industry but the entire electrical supply and contracting industry and serves the conventional distribution system well.

A realistic approach when making cost comparisons for the solid state ballast is to assume that the advent of these energy efficient devices will change the existing industry practice and pricing policies. The existing distribution system is set up solely to take and fill orders at the request of contractors and other users. The average selling price of a ballast sold through the existing distribution system is considerably less than the manufacturers suggested retail selling price.

In all probability we believe that an entirely new distribution system will be created to provide the necessary selling expertise, technical marketing, and support required by this new class of products. Perhaps some of those employed in the existing market system will choose to change over to these new products but we anticipate that most will not.

The new distribution system will in all probability resemble the office equipment, copier, and telecommunications market approach rather than the existing electrical supply distribution system. The principle differences being in the ability to provide the customized service and support required for this new class of products and systems with each tier of the distribution pricing their markups or profits more in relation to added productivity than to the blind markup/profit scheme now utilized in the lighting industry.

This new approach makes a big difference in cost savings and benefit projections to the end user. Luminoptics Corporation expects to sell their 200 watt HPS solid state ballast to the end user for a premium of $64.00 including a $20.00 allowance for installation. The $20.00 initial installation charge will not be utilized in calculations for the "new" market or where the ballasts are expected to be purchased as replacements for existing conventional ballasts which have failed nor where the labor charges would have been incurred anyway.

The ground rules for the following series of cost benefit calculations (the assumptions) are as follows:

Time Frame:	1982 - 1983 for medium - large volume production
Energy Cost Escalation:	1% per year in real terms
Base Energy Cost:	5 Cents per KWH
Depreciation Schedule:	Straight Line Method
Ballast Premium Cost:	$44.00
Installation Cost:	$20.00
Energy Savings:	45%
Corporate Tax Rate:	44%
Investment Tax Credit:	10%
Salvage Value:	10%
Useable/Economic Life:	20 Years

Mr. J.W. Griffith, K.G. Associates, Fort Worth, Texas was most helpful in supplying some of the information for the calculations although he did not assist nor does he warrant the conclusions. The conclusions drawn below are the authors. All calculations were made in accordance with the American Management Association's "The Systematic Energy Conservation Management Guide" volume 9, Analyzing Capital Projects in Energy Conservation.

There are three commonly used methods of determining the value of energy conservation projects. Perhaps the most accurate is the Discounted Cash Flow Method (DCF) or Internal Rate of Return (IRR). DCF measures all economic consequences of a project including the time value of money used for this purpose. It is time consuming to calculate DCF as one must do a cash flow projection and take into account the time value of money, tax rates, depreciation, Investment Tax Credit (ITC), and other costs and benefits. Simply stated, if the DCF is above the marginal cost of money then the project is worhwhile and should be pursued.

Simple return on investment (ROI) does not take into account the time value of money, life of equipment, unequal earnings in different years, or other factors which apply. It does however, provide a quick and easy comparison between one like project and another.

The least desireable method for conducting investment analysis, in the authors opinion, is the pay back method. This method determines the number of years it takes to recoup a capital investment but gives little indication as to how the investment effects the overall financial plans of the business.

A DCF calculation was made using the ground rules defined above and it was found the the solid state 200 watt HPS lamp ballast would have an Internal Rate of Return (IRR) of almost 23% by 1982. Current industry thinking is that if the IRR is above 18-20% then the project is worthwhile and should be pursued. The reader should note several factors in the calculation that could alter the IRR in a positive way. The energy cost index used was 1% per year which is current DOE thinking but is not related to the increases over the last half dozen years. Second, the calculation assumes that the ballast will be purchased for retrofit to conserve energy (and dollars). Where conventional ballasts are replaced with solid state ballasts at time of failure or during periods when maintenance has to be performed anyway, the IRR will increase. The cost of the ballast ($44 premium) could be less if larger quantities were manufactured and the assumption was that only .5% of the market would be captured during this period. Also, the cost of the conventional ballast may be higher than projected which would reduce the premium and increase the IRR. Another factor that effects IRR is availabliity of energy. If a company has to reduce energy consumption to preserve existing work habits there is an additional monetary benefit which will have a positive impact on the IRR. Last but by no means least is the Energy Conservation Tax Credit which is expected to be in addition to the ITC. If a meaningful Energy Credit is passed by the Congress of 22 to 25% it would put the IRR to such a level that virtually no Company could afford not retrofit to energy efficient lighting systems.

The second method or simple Rate of Return measures cash recapture rate and is defined as follows:

$$\text{Simple pay-back (ROI)} = \frac{\text{annual earnings (savings)}}{\text{capital investment}}$$

$$37.26\% = \frac{\$23.85}{\$64.00}$$

The assumption above is that the ballast will be retrofitted as an energy and dollar conservation program and will include a $20.00 installation cost. Where the devices are installed as existing units fail, the simple ROI reaches 54%

The third method or pay-back is defined as follows:

$$\text{Simple pay-back (years)} = \frac{\text{capital invested}}{\text{net savings (per year)}}$$

$$1.84 \text{ years} = \frac{\$44.00}{\$23.85}$$

The above assumes that the ballast will be installed as existing units fail. Where the ballast requires a $20.00 installation charge the pay-back stretches to 2.68 years.

The above is not intended to be all inclusive and covers only the installation of one ballast in a "typical" corporate environment and is intended for reference only. There are many variables which impact ROI and IRR calculations, not the least of which is utility rate structure, geographical area, and internal policies and including accounting rules (which vary considerably). There is no substitute for performing the calculations using a specific Corporate structure after a demonstration and test at which time firm numbers are established. The reader is again cautioned that these numbers are for reference only and intended to give one some idea as to the potential financial impact of the solid state HPS ballast.

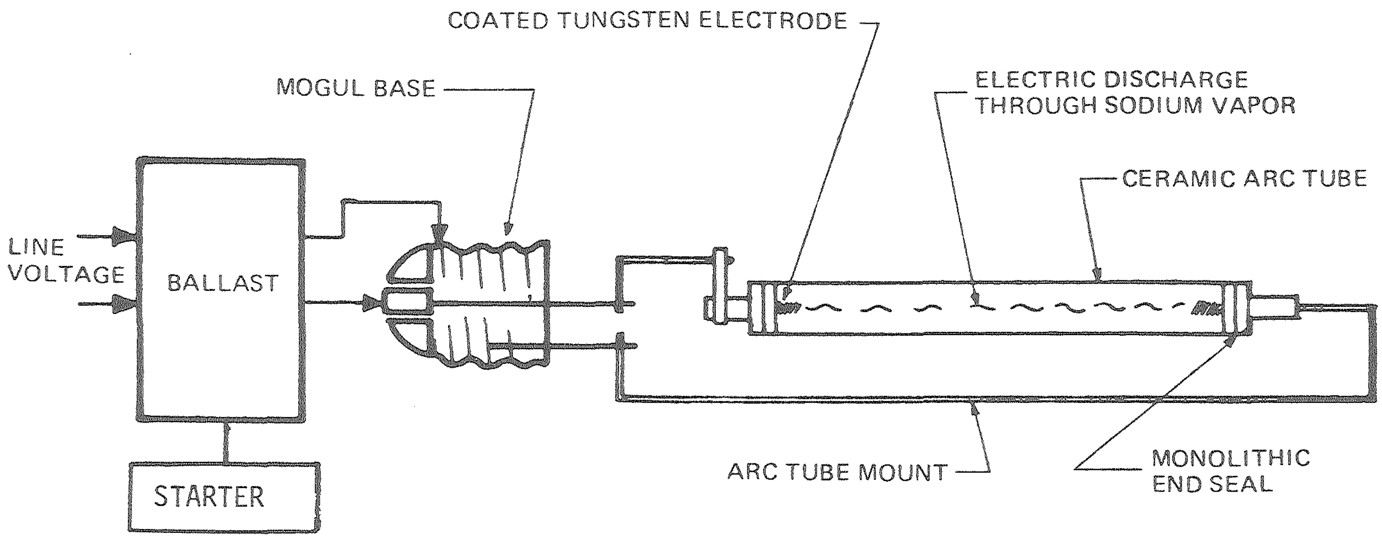


FIGURE 5-1

BLOCK DIAGRAM - CONVENTIONAL BALLAST

8661-01 HPS SOLID STATE BALLAST (200 WATT)

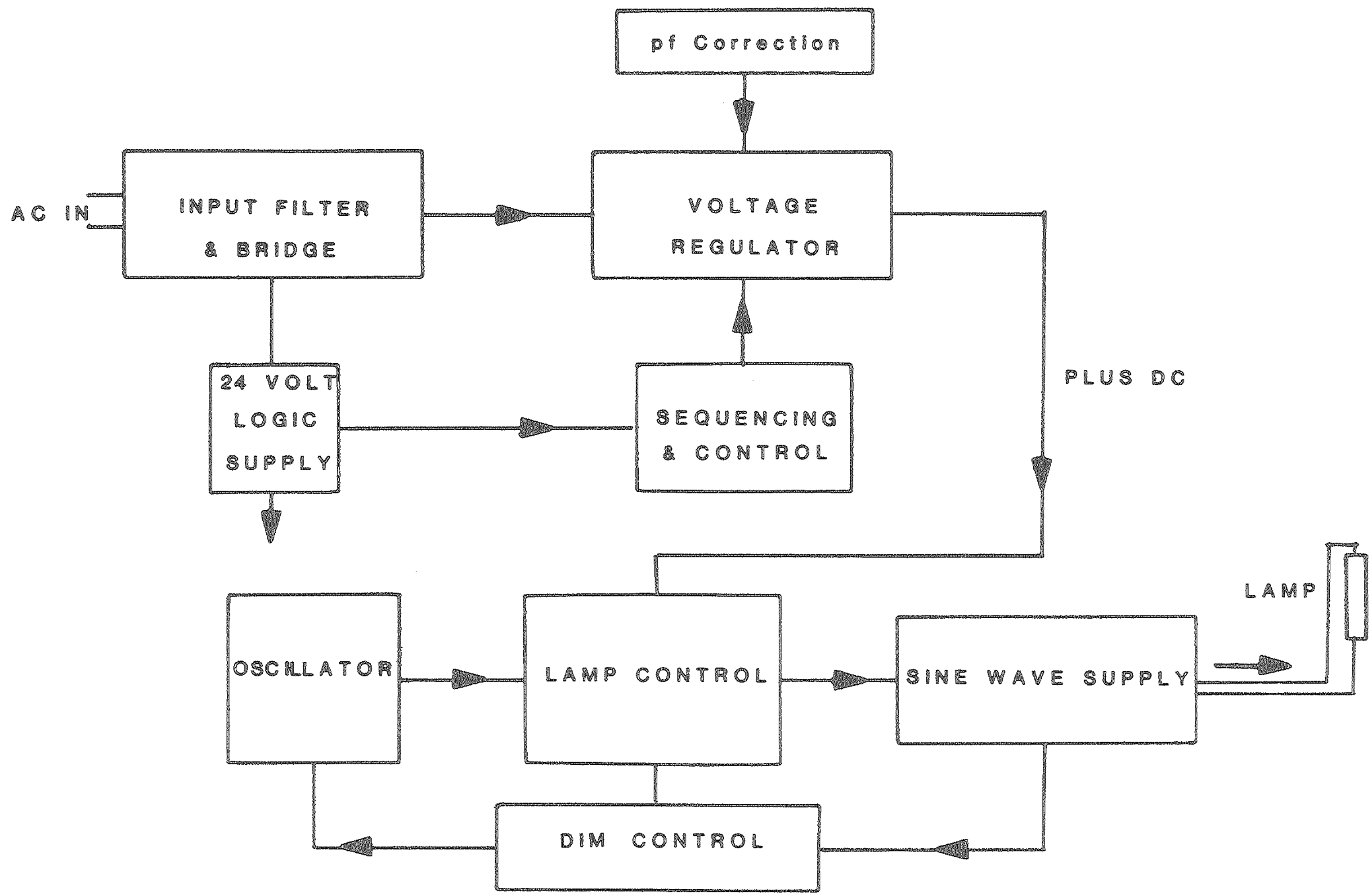


FIGURE 5-2

150 WATT HPS LAMP
97Ω 220 VOLT REFERENCE BALLAST

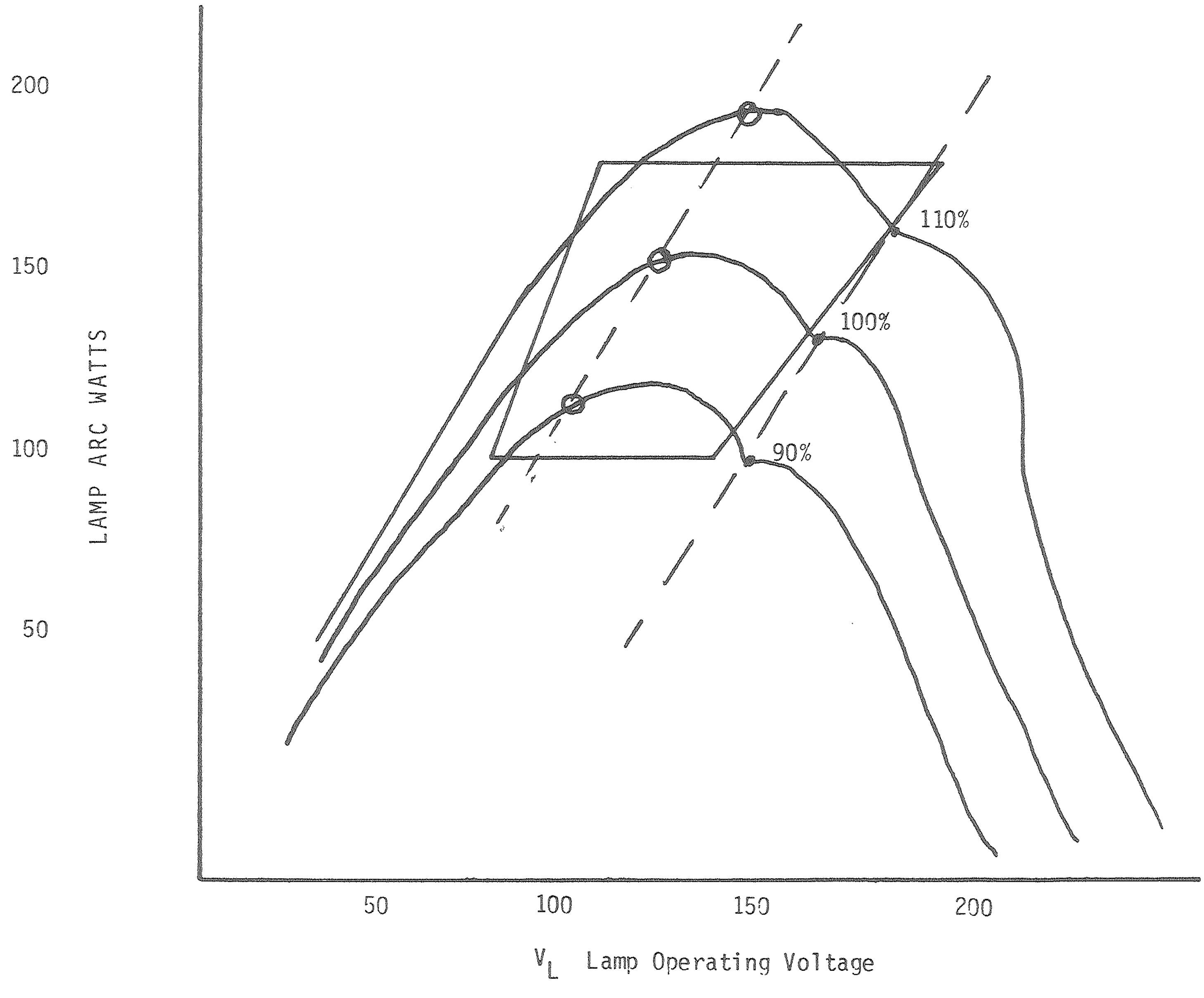


FIGURE 5-3
LAMP WATTS ON AN UNREGULATED REFERENCE BALLAST

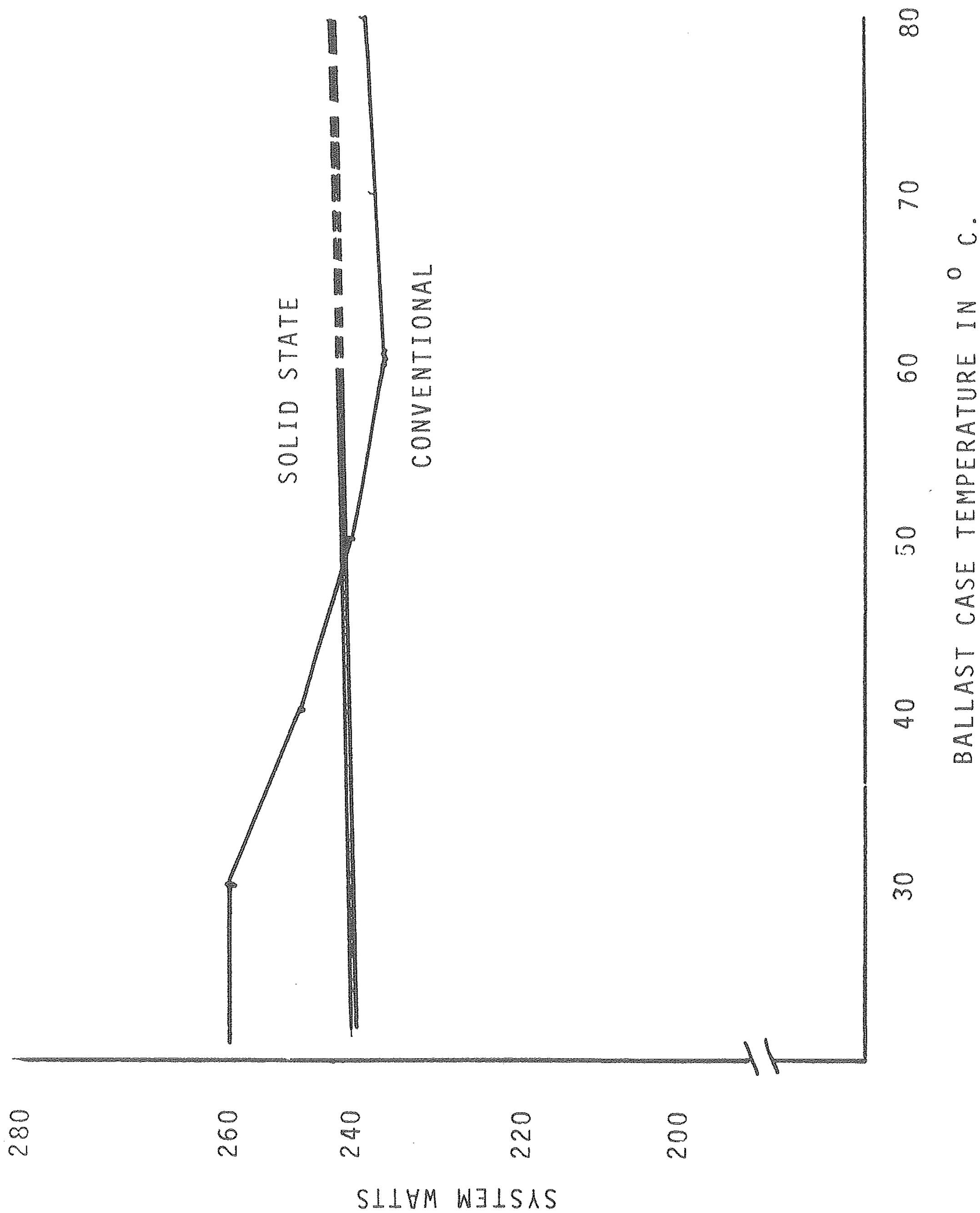
FIGURE(TABLE) 5-4

LUMINOPTICS CORPORATION
SUMMARY OF PERFORMANCE DATA - 8661-SERIES BALLAST
SOLID STATE VRS CONVENTIONAL
(Pre-Production Run)

	WORST	BEST	AVERAGE	CONVENTIONAL
INPUT				
Input voltage	Average 250 to 305 VAC IN			2 77
Power factor[1]	.92	1.00	.936	.98
Line regulation ± %[2]	2.46	.40	1.32	9.70
I input @ 277V & 50 ohm load	1.04	.89	.97	1.43
Watts in @ 277V & 50 ohm load	266	236	256	390
Line to lamps watts regulation from 250-305 Volts in ± %[3]	5.20	.3	2.39	390
OUTPUT				
Lamp voltage @ 30 ohms (RMS)			76.90	79.30
Lamp voltage @ 50 ohms (RMS)			104.80	136.8
Dimming range in % max light	10.00	24.50	17.60	
Open circuit voltage (RMS)	222	245	233	
Power supply ripple (Vpp)[4]				
@ 20KHZ	1.49	.50	.90	
@ 120 HZ	9.00	5.50	7.80	
Efficiency (Po/Pin)				
@ 30 Ohm load in %	84.10	87.60	86.00	75.70
@ 50 Ohm load in %	86.90	91.00	88.90	79.60
Lamp watts regulation in %	7.00	1.80	5.50	
Relative system performance[5] Index (Reff)	114.1	127.1	117.6	77.0

..../42

FIGURE 5-5



TEMPERATURE EFFECTS ON BALLAST SYSTEM

REPEATABILITY COMPARISON BETWEEN 200 WATT HPS CONVENTIONAL BALLAST AND THE LUMINOPTICS 8661-01 SOLID STATE BALLAST

	BRAND X			BRAND Y		
PARAMETER	# 3	# 4	# 12	# 7	# 14	# 15
CONVENTIONAL BALLAST						
P_{in}	270	257	278	245	263	238
L_o	1,700	1,700	1,820	1,500	1,700	1,460
LUMINOPTICS SOLID STATE BALLAST						
P_{in}	227	227	227	227	227	225
L_o	1,570	1,640	1,580	1,600	1,630	1,600

Where: P_{in} Equals power input expressed in watts
L_o Equals relative footcandles

All tests conducted at ambient temperature (23^o C) at 277 VAC input utilizing a Tecktronic J-16 Photometer.

Lamp serial numbers 7, 14 & 15 are manufactured by X (refer to text) and 3, 4 & 12 are manufactured by Y.

The purpose of this test was to ascertain the consistancy or repeatability of utilizing different lamps with the same ballast. From the data one learns that with the conventional ballast there is a 7% spread in light output between Manufacturer Y's lamps and a 14% spread between lamps manufactured by X. If an end user were to interchange lamps manufactured by both X & Y he could expect a difference in light output of 19.8% utilizing the conventional ballast.

When utilizing the solid state ballast one obtains a 2% spread in light output for those lamps manufactured by W and a 4% spread for those lamps manufactured by manufacturer X and an overall spread of 4.3%.

This would tend to indicate that the conventional ballast is in the order of 4-5 times less consistent than the electronic ballast in terms of predicting the light output available if one does not specify a particular lamp manufacturer and as much as 3-4 times less predictable even when the manufacturer is specified.

The reader should also bear in mind that these tests were run only at the conventional ballast's nominal input voltage and that there may be even a greater variation in performance as the input voltage varies from design center.

6.0 TASK IV MARKET POTENTIAL STUDY

6.1 Task Statement:

A. Prepare a market description of the present annual shipments and sales for the HID ballast market. Divide the analysis in terms of the following:

1. Ballast types (Metal Halide, Mercury Vapor or High Pressure Sodium)
2. Sizes (power ratings).
3. Input voltages.

B. Prepare a matrix to compare and assess HID applications as system characteristics.

6.2 Market Potential; A market potential study should begin with an analysis of current and past shipments, types of products shipped, and future trends within the industry. Unfortunately it is not possible to gather reliable market statistics on current and past product shipments for a number of reasons which will be explained. Therefore assumptions have been made regarding shipments, the value of those shipments and future industry projections.

The starting place for gathering statistics for the lighting industry is the U.S. Department of Commerce, Bureau of the Census. The Commerce Department gathers industry reports on shipments of ballasts and lamps and provides basic input in developing a market profile.

Table 6-1 lists HID ballast shipments by Department of Commerce product identification codes. Note that the coding for lamp ballasts was altered and/or combined between the 1972 and 1977 to prevent disclosure of individual companies shipments.

One should clearly understand that the Census Bureau gathers and publishes statistics on product shipments and their value, as reported by industry. If all Companies do not report shipments (which they don't, nor are they required to), and the value that is placed on the shipments is understated, then the statistics reported by the Commerce Department are subject to interpretation. The purpose of the CENSUS OF MANUFACTURERS reports is not to validate or warrant the figures gathered and therefore one must look to other sources to develop a picture of the total market.

For instance, according to the bureau of census figures, in 1967 the total number of HID ballasts shipped was 1.1 million units at an average cost of $11.45. In 1972 13.0 million units were shipped at a cost of $3.75 each. In 1977, 2.1 million ballasts were shipped at an average cost of $18.52.

The above data suggests that 1972 was a banner year for the HID ballast manufacturers in terms of the number of units shipped but was probably a very unprofitable year in terms of income because the average price of each unit shipped dropped almost 66% from their 1972 level. However, by 1977 the demand for HID ballasts had decreased to 3.7 million units but the price increased approximately 490% from 1972 levels.

If the industry had such a drastic increase in capacity, followed by an inordinate drop in market demand, one would expect to find the available increase in production capacity filled with similar products, which doesn't appear to be the case. Looking at a similar product, the production capacity and demand for fluorescent ballasts has remained relatively stable at about 2.5% per year (long term rate). What appears to have happened is that the number of HID ballast manufacturers has increased and become decentralized (away from the dominant suppliers) and their output is not subject to reporting.

This tends to be borne out by other reports published by the Department of Commerce and by a number of independent research organizations. For instance, the shipments of all gaseous discharge lamps, including HID, has been relatively stable from the period 1973 to 1979 (see MQ-36B(79)-4 April, 1980, Current Industrial Reports), at about 450 million lamps annually. Shipments of all transformers from the period 1974 to 1979 were also stable and increased at about a 4% rate (see US Industrial Outlook code SC3612). Shipments of lighting fixtures was also stable being at about a 5% annual growth rate.

It is reasonable to assume that a portion of the lamp sales and fixture sales will require a ballast. If lamp sales and fixture sales have not decreased, then it is logical to conclude that HID ballast shipments have maintained during this period.

Additionally, the valuation stated in the Commerce Department reports seem understated. This is probably due to combined reporting of commercial industrial grade ballasts with the very inexpensive type used in the home/ farm market, which tends to dilute the average price.

Based on discussions with various manufacturers in the industry who did not want to be identified, the total number of ballasts shipped in 1972 appears correct (Figure 6-1). Also the value of the shipments was probably higher than stated.

It was also felt that the total HPS market was approximately 10-12% of the total HID market at that time and that the long term market was growing at a 3% year compounded rate with the HPS segment of the market acheiving higher growth rates (approaching 25% in some years). This growth is at the expense of mercury vapor and metal halide due to the greater efficiency of HPS lamps.

Figure 6-2, was also developed from discussions with leading industry figures and other sources including the Census of Manufacturers data for fixtures, lamps, and ballasts.

The forecast assumes a long term growth rate for all industrial and commercial grade HID ballasts which we feel is reasonable. The reader should understand that this forecast is the writers best attempt to fix variables and to utilize diverse data in trying to arrive at a simple presentation. The reliability of the estimate can (and hopefully will be) questioned by those manufacturers which have access to proprietary market statistics.

With regard to the value of HID shipments, the author feels that Figure 6-3 reflects accurately the value of shipments in the HID market area. Figure (Table) 6-4 establishes the methodology for arriving at an average factory billing price and includes all factory costs plus profit in determining the factory billing price.

The charts and tables have been prepared from reliable published suggested retail prices which were then reduced by appropriate amounts for similar industries to arrive at a probable factory billing price.

There are in excess of 280 products in the sample. Because the markup of any company product sales for a given period is confidential and not open to scrutiny by outsiders, certain assumptions were made with regard to the "factory billing price" used to determine the total value of all shipments.

The author believes the assumptions are valid for a mature industry such as the ballast industry. These are:

1. The suggested retail price for each product is discounted to 45% ("the discounted retail price") to arrive at the factory billing price.

2. The probable average factory billing price is closer to the discounted average retail price plus the lowest price divided by two, than to the average discounted catalog price.

3. That the suggested retail price is 4-5 times the base material cost plus standard labor hours cost and is probably closer to 4 because of the very competitive nature of the industry.

Also included in Figure 6-3 is a line which indicates the market potential for the solid state ballast if one is available. The average factory billing price for the solid state ballast includes a premium which reflects the solid state ballast's higher costs. The premium is pegged at $44 for the HPS and MH ballasts and $20 for the Mercury ballast. These premiums are based on the solid state ballst's better productivity and their ability to pay for themselves in under three years in commercial applications. It is anticipated that the premium will be reduced as large numbers of solid state ballasts are manufactured and therefore the average time to recover initial cost will also be reduced accordingly.

The reader should also be aware that the forecasts cover only commercial/industrial grade ballasts and not the inexpensive types manufactured for the home/farm market.

Figure 6-5 describes the various HID lamp sources currently available according to their rated lumen output, color rendering index, and efficacy. Color rendering index (CRI) describes the relative rating of the lamp in terms of color with 100 being the highest (sunlight), For more detailed explanation of CRI, see the IES Handbook, fifth edition.

With the exception of small wattage mercury vapor lamps which are used as security lights for home and farm applications, the sources listed are used mainly in commercial/industrial and street light applications.

FIGURE(TABLE) 6-1

SUMMARY OF HID BALLAST SHIPMENTS AND VALUE
(in millions of units and millions of dollars)

SIC Product Code	Description	1967 quantity	1967 value	1972 quantity	1972 value	1977 quantity	1977 value	1979 quantity	1979 value
36125-43	Mercury Vapor								
36125-47	Multiple, all	1.1	12.6	13.0	48.7	1.1	16.1		
36125-49									
36125-44									
36125-45	Metal Halide	*	*	*	*	.4	7.9		
36125-46	Sodium Vapor	*	*	*	*	.6	14.9		
					Total	2.1	38.9		

* Included in other reporting categories to prevent disclosure of trade information.

Source: Department of Commerce, Census Bureau

..../50

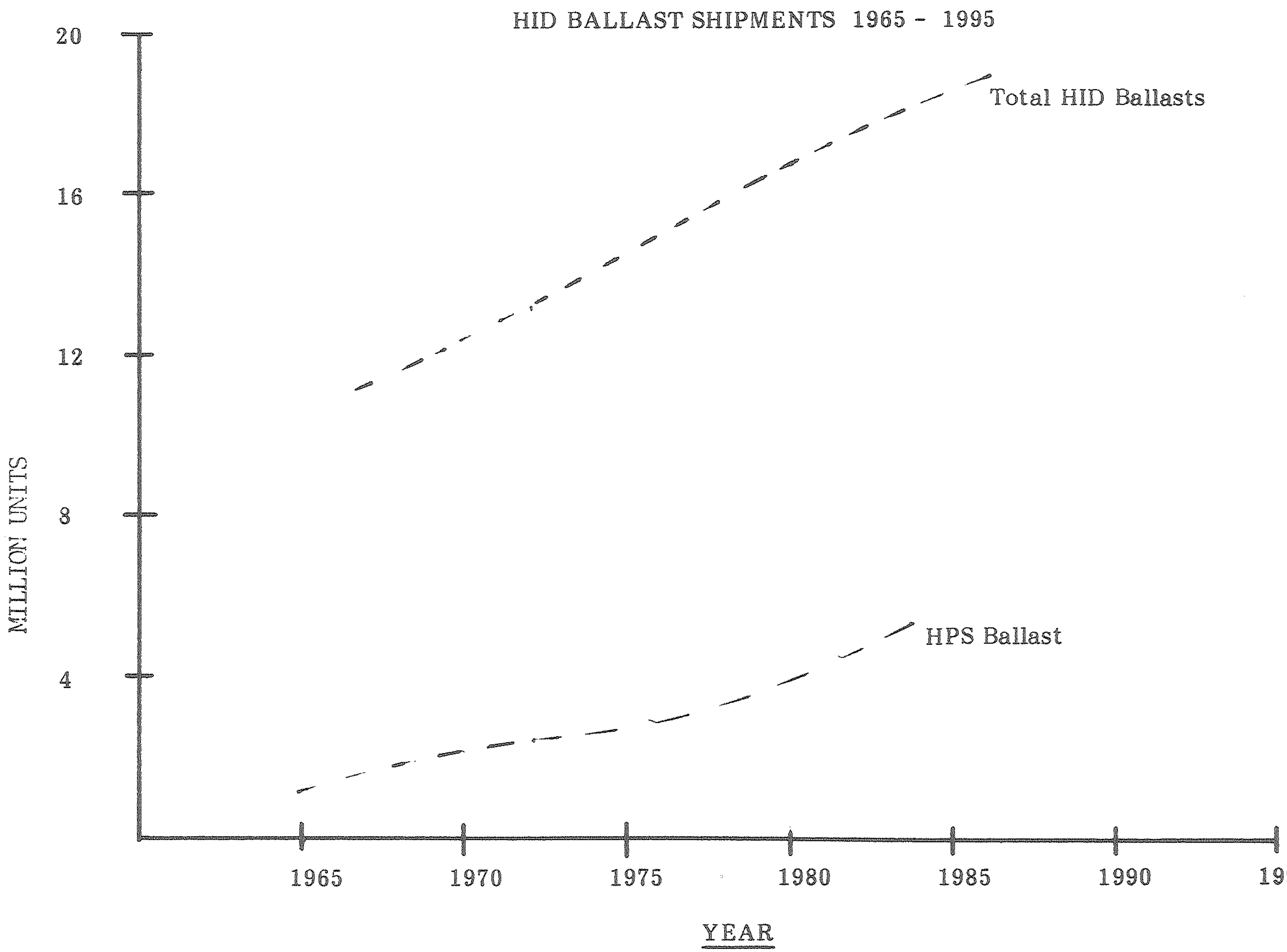

HID BALLAST SHIPMENTS 1965 - 1995
20
16
12
8
4
MILLION UNITS
Total HID Ballasts
HPS Ballast
1965
1970
1975
1980
1985
1990
1995
YEAR

FIGURE 6-2

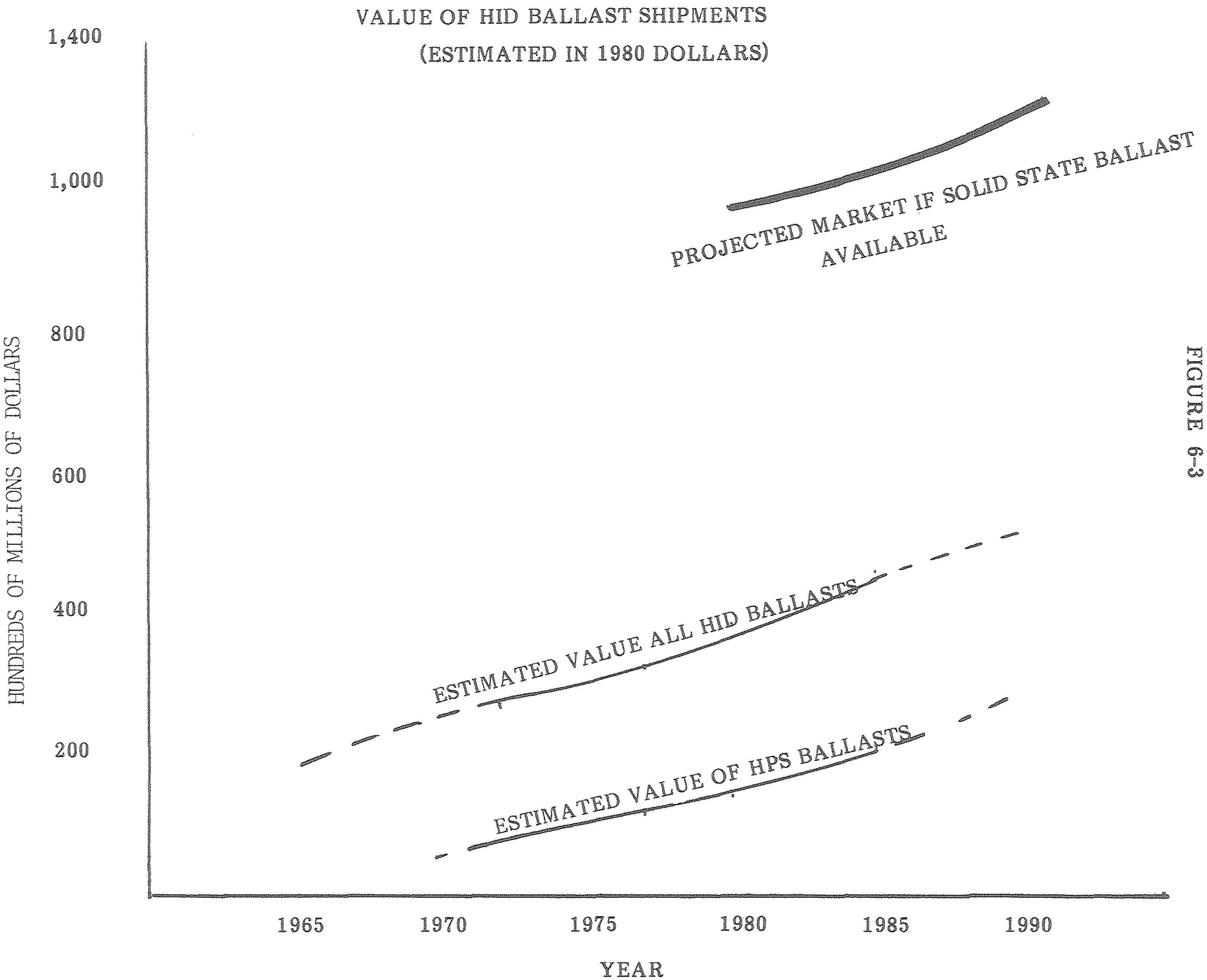

VALUE OF HID BALLAST SHIPMENTS
(ESTIMATED IN 1980 DOLLARS)
HUNDREDS OF MILLIONS OF DOLLARS
1,400
1,000
800
600
400
200
PROJECTED MARKET IF SOLID STATE BALLAST AVAILABLE
ESTIMATED VALUE ALL HID BALLASTS
ESTIMATED VALUE OF HPS BALLASTS
1965
1970
1975
1980
1985
1990
YEAR

FIGURE 6-3

FIGURE(TABLE) 6-4

HID BALLAST PRICING ANALYSIS

Mercury Vapor:	Number of samples:	145
	Average retail price:*	$44.82
	Highest in sample:	$76.97
	Lowest in sample	$25.00
Metal Halide:	Number of samples:	88
	Average retail price:*	$60.78
	Highest in sample:	$99.94
	Lowest in sample:	$29.78
High Pressure Sodium:	Number of samples:	48
	Average retail price:*	$78.79
	Highest in sample:	$82.48
	Lowest in sample:	$75.93
All HID BALLASTS	Number of samples:	281
	Average retail price:*	$61.46
	Highest in sample	$99.94
	Lowest in sample	$25.00

* Manufacturer's suggested retail price.

ASSUMPTIONS

(List price is 4 x (labor and materials))

Probable factory billing price is .45 x average list price.

Mercury Vapor:	Average retail price:	$44.82
	Probable average factory billing price:	$20.17
	High factory billing price:	$34.63
	Low factory billing price:	$11.25

Use for all calculations:

Average + low ˚/. 2 or $15.71

Metal Halide:	Average retail price:	$60.78
	Probable average factory billing price:	$27.35
	High factory billing price:	$44.97
	Low factory billing price:	$13.40

Use for all calculations:

Average + low˚/. 2 or $20.38

High Pressure Sodium:	Average retail price:	\$78.79
	Probable billing price:	\$35.46
	High factory billing price:	\$37.12
	Low factory billing price:	\$34.17

Use for all calculations:

Average + low °/. 2 or \$34.82

FIGURE(TABLE) 6-5

PARAMETER	MERCURY VAPOR	METAL HALIDE	HIGH PRESSURE SODIUM	LOW PRESSURE SODIUM
Lamp efficacy in lumens per watt (LPW)	42	73	104	180
Color rendering index (CRI)	51	72	21	21
LUMEN OUTPUT				
2,000	Yes(1)	No	No	No
2,000 to 10,000	Yes(5)	No	Yes(3)	Yes(2)
10,000 to 20,000	Yes(1)	Yes(2)	Yes(3)	Yes(1)
20,000 to 50,000	Yes(3)	Yes(4)	Yes(3)	Yes(1)
50,000	No	Yes(3)	Yes(1)	No

Notes: Number In ( ) indicated number of lamp sizes available within the range.

Lamp efficacy (LPW) is derived using three lamp sizes and dividing mean lumens by rated arc watts.

MATRIX OF LAMP PERFORMANCE AND AVAILABLE SIZES

7.0 TASK V BALLAST DELIVERY

7.1 Task Statement:

A. Construct, test and package suitably reliable, representative, engineering prototype ballasts, and deliver six (6) of the units to Lawrence Berkeley Laboratory. LBL will submit these units to an independent test laboratory to verify the electrical and photometric performance. The deliverable should include the HID lamp used in the in-house testing.

B. Documentation of submitted units:

1. Mechanical
2. Stress analysis reports
3. Electrical, photometric performance
4. Operating instructions

C. Provide liasion services as determined by LBL during the LBL test period.

7.2 Ballast Construction, Electrical; The ballast supplied under this contract has the manufacturers designation (model number) 8661-01 and is designed to operate a 200 watt HPS lamp at an input voltage of 277 Volts AC. Electrical design of the ballast was completed in late spring of 1979.

The 8661-01 ballast is packaged to operate in a standard industrial type indoor Lighting fixture. A catalog cut of this particular fixture is included herein as Figure 7-1.

The ballast consists of three (3) printed circuit boards (PCB) which are housed in a metal container. Drawing EXD-8661-01 is a top assembly drawing, and shows the basic mechanical assembly. Schematic drawings, assembly drawings, test and Q.C. proceedures are considered proprietary information by the Company and are not included herein, nor are they required to be included.

Table 7-2 lists performance data obtained with the first nine solid state ballasts tested and gives the reader some insight into the performance variations from unit to unit. It is intended that in future designs that production tolerences will be tightened up so that the unit to unit performance will vary less than + or - 2%.

7.3 Ballast Construction, Mechanical; The solid state ballast consists of one each of the following parts: (1) power supply module; (2) a lamp driver module; (3) a master board; and a metal housing which provides the basic structure for the PCB's and also serves to heat sink the major components. Both the lamp driver and power supply are mounted on plug in type PCB's for ease of removal. These two boards plug into the master board which also serves as an interconnection module to the external wiring.

Overall dimensions of the metal housing are: 6-5/8 " long by 4- 3/8 " high by 4- 1/4 " wide. The approximate weight of the prototype units is 4 pounds 14 ounces including the external wiring harness.

With a slight variation in the packaging layout the same unit can be made to fit in most outdoor "cobra head" type fixtures commonly in use in the United States as well as most industrial indoor fixtures.

7.4 Operating Instructions; Appendix B contains the operating instructions and interconnection diagram for the solid state ballast.

7.5 Other Information; A total of six ballasts were constructed and delivered under this contract. Before shipment the units were tested and operated for a total of over three hundred hours. During that time they were cycled on and off an average of twice per ten hour day (5 hours on/ten minutes off) and were subjected to periodic line transients, over voltage, under voltage, instant restart, and other stressfull conditions with only one failure. After delivery two failures occurred. The first was because of a disconnected input lead which was inadvertently pulled out of it's connection during testing and the second was traced to failure of an integrated circuit in a circuit with no particular long term significance. In addition, the power supply modules were run in seperately for an additional two hundred hours without failure.

It is intended that Phase II production development work will correct a few items found to be deficient in the original ballast design. These items include:

1) Reconfigure the mechanical design to develop various alternative package configurations as appropriate.

2) Extend the dimming range from approximately 19% to 50%+.

3) Change some of the interface circuitry to conform with the presently designed external interface equipment such as the photocell modules, battery interface module, and other ancillary equipment.

4) Reduce the production tolerences in unit to unit performance to tighten the average preformance characteristics. At the same time the lamp aging (trapazoid) tolerence will be broadened if required.

FIGURE 7-1

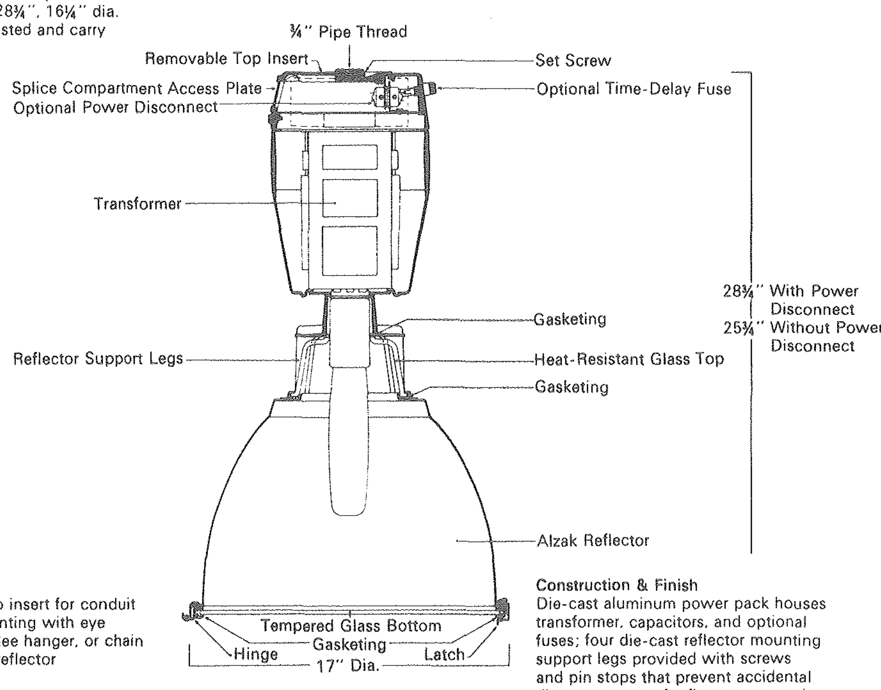
TYPICAL INDUSTRIAL FIXTURE, WITH SPECIFICATIONS

250-Watt High Pressure Sodium 16" Enclosed **SEC 60-67**

250-Watt High Pressure Sodium 16" Enclosed
Single-lamp high pressure sodium luminaire for lighting medium- and high-bay industrial interiors where a closed-bottom, closed-top design with up-light or a U.L. damp-location label is desired; die-cast aluminum power pack has removable top insert which attaches to the supporting system prior to hanging; optional power disconnect eliminates the need for power hooks; optional accessible time-delay fuse (2 for 480-volt unit); fixture height 28¾", 16¼" dia. reflector; units U.L. listed and carry Union labels.

Lamps & Wiring
Prewired power packs are U.L. listed for 90° primary wiring and approved for continuous operation in 55° C. (131° F.) ambient temperature; grounding screw provided in removable top insert; HPF constant-wattage transformer maintains lamp output ± 5.0% over supply voltage of ± 10%.

Reflector
16¼" diffuse Alzak reflector gives wide-spread distribution (1.69 S/MH and 39° shielding), and spread distribution (1.02 S/MH and 43° shielding) with higher lamp position; heat-resistant glass top and ¼" tempered glass bottom have silicone rubber and sponge gasketing which filters out dirt as fixture cools; bottom has aluminum frame secured by stainless-steel hinge and two stainless-steel latches.



Installation
¾" pipe thread in top insert for conduit mounting or for mounting with eye bolt (by others), Hydee hanger, or chain and hook; enclosed reflector supplied assembled.

With power disconnect:
Insert is mounted directly to fixture support (grounding screw provided) and pre-wired power pack is slid in place (locking screw provided).

Without power disconnect:
Top fitting connected to mounting pipe or conduit (grounding screw provided), power pack is slid in place (locking screw provided) and wiring is spliced through wiring chute access.

Construction & Finish
Die-cast aluminum power pack houses transformer, capacitors, and optional fuses; four die-cast reflector mounting support legs provided with screws and pin stops that prevent accidental disengagement of reflector; exposed surfaces of power pack and reflector legs treated with five-stage coating of zinc phosphate and finished in hot-bonded baked gray enamel; zinc-plated steel fasteners and stainless-steel screws for housing assembly.

Reproduced with permission from Robert D. Munson, Day-Brite Lighting Division, Emerson Electric Co. 1015 S. Green St. Tupelo, MS 38801, February 24, 1981

FIGURE 7-1, continued

DAY-BRITE 250-Watt High Pressure Sodium 16" Enclosed — SEC 60-68

Lamp Information 250-Watt W/16" Reflector	Fixture Height	Reflector Diameter	Approx. Shp. Wgt.	Catalog No. Narrow	Catalog No. Wide	Catalog No. Suffixes
120-Volt Unit	25¾"*	16¼"	60 lbs.	E25L12N-ADE16	E25L12W-ADE16	Power Disconnect-D
208-Volt Unit	25¾"*	16¼"	60 lbs.	E25L20N-ADE16	E25L20W-ADE16	Ex. E25L20WD-ADE16
240-Volt Unit	25¾"*	16¼"	60 lbs.	E25L24N-ADE16	E25L24W-ADE16	
277-Volt Unit	25¾"*	16¼"	60 lbs.	E25L27N-ADE16	E25L27W-ADE16	
480-Volt Unit	25¾"*	16¼"	60 lbs.	E25L48N-ADE16	E25L48W-ADE16	

Note: If fusing is desired, specify on order, "With Fuses."

*28¾" With Power Disconnect

Simplified Lighting Design Table**

Mtg. Ht. Above Work Plane	Narrow 13'	18'	22'	26'	30'	34'	Wide 13'	18'	22'	26'	30'	34'
Room Size	No. of Fixtures Required for 100 Footcandles Maintained*											
30' x 30'	10	12	14	16	18	20	10	12	14	17	20	23
x 50'	16	18	20	23	24	27	16	18	21	23	26	30
x 100'	30	33	37	40	42	46	30	33	36	40	43	49
x 150'	44	49	54	58	61	67	44	48	52	56	62	69
40' x 40'	17	19	21	23	25	28	16	18	21	23	26	29
x 60'	24	26	29	31	33	37	23	26	28	31	34	38
x 90'	34	38	41	43	47	50	34	37	40	42	47	51
x 150'	57	60	64	69	74	79	55	59	64	68	72	79
x 200'	75	79	85	90	96	100	72	77	85	88	92	100
50' x 50'	25	27	29	32	34	36	24	27	29	31	34	37
x 85'	40	43	45	49	52	54	39	42	45	48	51	55
x 150'	68	73	77	80	85	90	66	70	75	78	83	88
60' x 60'	34	37	40	41	45	47	33	36	38	41	44	47
x 100'	64	58	61	64	68	72	53	56	60	62	66	70
x 200'	105	111	116	121	125	132	102	107	112	118	123	127
75' x 75'	51	54	57	60	63	68	49	53	55	60	62	65
x 120'	79	83	87	90	94	97	76	80	84	89	92	96
x 200'	129	136	140	145	148	153	123	131	135	140	145	153
x 300'	195	201	207	214	222	226	185	193	200	207	214	221
100' x 100'	88	92	95	98	102	106	84	89	92	97	101	104
x 200'	170	175	181	184	191	197	163	170	173	178	185	194
x 300'	251	259	267	272	281	286	240	247	258	273	272	281
150' x 150'	188	194	200	204	211	214	180	186	194	197	204	211
x 250'	309	318	324	329	340	346	296	305	309	318	323	334
x 400'	494	502	510	517	525	543	466	480	488	495	509	517
200' x 200'	330	335	344	351	356	362	312	320	330	335	346	351
x 300'	487	502	510	518	521	525	460	480	488	495	502	510
x 400'	650	660	670	680	690	702	615	632	640	650	660	670

**For 50-30-20% Reflectance (No. of fixtures may vary slightly with layout)

Candlepower Distribution Curve

Angle	Narrow	Wide
5	10514.	6151.
15	9156.	6936.
25	8151.	7806.
35	7062.	7851.
45	2794.	4935.
55	578.	1029.
65	176.	251.
75	72.	84.
85	33.	30.
95	72.	39.
105	137.	91.
115	482.	147.
125	859.	486.
135	1166.	825.
145	998.	909.
155	276.	385.
165	64.	60.
175	75.	74.

Coefficients of Utilization

Zonal Cavity Method

Narrow pfc 20 / pcc	70		50		10		Wide pfc 20 / pcc	70		50		10	
pw	30	10	30	10	30	10	pw	30	10	30	10	30	10
RCR							RCR						
1	.69	.68	.65	.63	.56	.56	1	.72	.70	.68	.66	.61	.60
2	.62	.60	.59	.57	.52	.51	2	.64	.62	.61	.59	.56	.54
3	.56	.54	.54	.51	.48	.47	3	.58	.54	.55	.53	.51	.49
4	.51	.48	.49	.46	.44	.43	4	.52	.48	.50	.47	.46	.44
5	.46	.43	.44	.42	.41	.39	5	.46	.43	.45	.42	.42	.39
6	.43	.39	.41	.38	.38	.36	6	.42	.38	.40	.37	.38	.35
7	.39	.36	.37	.35	.35	.32	7	.37	.34	.36	.33	.34	.31
8	.35	.32	.34	.31	.31	.29	8	.33	.29	.32	.29	.30	.28
9	.32	.29	.31	.28	.28	.26	9	.29	.26	.28	.25	.26	.24
10	.29	.26	.28	.25	.26	.24	10	.26	.23	.25	.22	.24	.21

Zonal Inflectance Method

Narrow floor 10 / ceiling		80		50		Wide floor 10 / ceiling		80		50	
wall		30	10	30	10	wall		30	10	30	10
RI	RR					RI	RR				
j	0.6	.33	.30	.31	.29	j	0.6	.30	.27	.29	.27
i	0.8	.41	.38	.39	.36	i	0.8	.40	.36	.38	.35
h	1.0	.45	.42	.43	.41	h	1.0	.45	.42	.44	.41
g	1.25	.50	.47	.47	.45	g	1.25	.50	.47	.48	.46
f	1.5	.54	.51	.50	.48	f	1.5	.54	.51	.52	.49
e	2.0	.58	.55	.54	.52	e	2.0	.59	.56	.56	.54
d	2.5	.61	.58	.57	.55	d	2.5	.62	.60	.59	.57
c	3.0	.63	.61	.58	.57	c	3.0	.65	.62	.61	.59
b	4.0	.65	.63	.60	.59	b	4.0	.67	.65	.63	.62
a	5.0	.67	.65	.62	.61	a	5.0	.69	.67	.65	.64

Maximum recommended spacing to mounting height ratio
Narrow 1.02 Wide 1.69

For complete photometric information request test numbers
Narrow #5829-250EG Wide #5814-250EG

DAY-BRITE LIGHTING DIVISION
EMERSON ELECTRIC CO
8100 W FLORISSANT
ST LOUIS, MISSOURI 63136
IN CANADA MARKHAM ONT
EMERSON

***Light Loss Factor Data**
LLF = Light Loss Factor
LDD = Dirt Depreciation
IES Category V Clean Annually

LLD = Lamp Lumen Depreciation
LLF = LDD × LLD = .71
LDD = Medium .82
LLD = .87 (Relamp @ 11,000 Hours)

FIGURE(TABLE) 7-2

LUMINOPTICS CORPORATION
SUMMARY OF PERFORMANCE DATA - 8661-01 BALLAST

BALLAST SERIAL NUMBER	1	2	3	4	5	6	7	8	9	AVERAGE
INPUT										
Input voltage		********************** TESTS WERE MADE OVER RANGE OF 235 to 305 VAC ********************								
Power factor[1]	.93	.95	.93	.94	.94	.93	.94	.93	.93	.94
Line regulation ± %[2]	.95	.90	1.73	.40	1.65	2.46	1.25	1.26	1.32	1.32
I input @ 277V & 50 ohm load	.98	1.01	.97	.89	.99	1.04	.94	.99	.96	.97
Watts in @ 277V & 50 ohm load	257	266	250	236	260	263	263	258	251	256
Line to lamps watts regulation from 250-305 volts in ± %[3]	.55	4.20	1.10	.30	1.70	5.20	1.90	.60	.80	2.39
OUTPUT										
Lamp voltage @ 30 ohms (RMS)	77.70	77.20	76.00	76.40	77.40	77.50	77.00	77.80	75.70	76.90
Lamp voltage @ 50 ohms (RMS)	106.80	104.50	104.40	101.10	105.00	105.70	105.30	106.40	103.80	104.80
Dimming range in % max light	18.50	14.50	17.00		16.50	19.00	18.11	20.63	16.61	17.60
Open circuit voltage (RMS)	233	245	222	240	230	241	242	222	225	233
Striker voltage peak	3,000	2,300	3,000	2,250	2,000	3,000	3,000	2,800	2,600	2,661
Power supply ripple (Vpp)[4]										
@ 20KHZ	1.40	.60	.50	1.00	1.00	1.40	1.20	1.00	1.20	.90
@ 120 HZ	9.00	5.50	5.50	8.00	8.00	9.00	9.00	8.00	8.00	7.80
Efficiency (PO/Pin)										
@ 30 ohm load in %	87.30	85.40	86.50	84.30	84.90	87.20	85.50	87.10	86.10	86.00
@ 50 ohm load in %	89.89	87.89	89.40	87.20	89.00	90.10	88.60	89.80	88.70	88.90
Lamp watts regulation in %	5.00	5.50	7.00	5.30	1.80	6.10	5.50	5.60	7.90	5.50
Relative system performance[5] Index (Reff)	116.7	115.4	120.0	127.1	115.4	114.1	114.1	116.3	119.5	117.6

19/....

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...../ 62

INDUSTRIAL TESTING LABORATORIES

BERKELEY—CALIFORNIA

APPENDIX A

PHOTOMETRIC
ELECTRICAL
MECHANICAL

TESTING
INSPECTION
DEVELOPMENT

INDUSTRIAL TESTING LABORATORIES

PHOTOMETRIC
ELECTRICAL
MECHANICAL

2813 Eighth Street
BERKELEY, CALIFORNIA 94710
(415) 848-3746

TESTING
INSPECTION
DEVELOPMENT

ITL TEST REPORT NO. 91664

PERFORMANCE CHARACTERISTICS OF SOLID STATE BALLASTS

Date: May 21, 1980

Tested for: UCB Lawrence Berkeley Lab
1 Cyclotron Road
Berkeley, CA 94720

Technical Coordinator for LBL: Dr. Rudy Verderber

Contract Administrator for LBL: Paul E. Marshall

Authorization: UCB Purchase Order 8407002, 3/26/80

DEVICES RECEIVED

A. Six (6) 277 volt Solid State HID Ballasts for 200W HPS Lamps. Lumenoptics Model No. 8661-01.

B. Two (2) 200W Westinghouse Ceramalux C200S66 High Pressure Sodium Lamps.

C. One (1) 277 volt input core-coil HID ballast for 200W HPS Lamp.
Marked on the core: ITT American Electric-Outdoor Lighting
P33353/24349, 200W, 277V, HPS

Capacitor: Aerovox P9404314E 14 mfd., 480V.
Starter Board: ITT-DY-12,23974.

Tests Requested

With the above, complete the following test and measurements for the six solid state ballasts and the standard core-coil ballast, with one of the 200 watt lamps.

A. Ballasts

1. input (power, voltage, current)
2. output (power, voltage, current)
3. input wave shapes (voltage, current)
4. output shapes (voltage, current)
   (for short (25kHz) and long (120 Hz) time scales)

B. Lamps

1. light output at equilibrium at center voltage
2. light output at plus or minus 10% center voltage
3. wave shape of light output at center voltage

C. Systems

1. Trace power input over range of voltages over safe operating range (data obtained by heating lamp).
2. Minimum starting voltage for cold start
   (do for 1 core-coil ballast and 2 solid state ballasts).

D. Determine for each ballast

1. System, lamp, ballast efficiency
2. Flicker index, % flicker
3. Power factor (power ÷ rms V x rms I)

Test Set-up: The equipment and instruments were arranged as shown in the diagram on the following page.

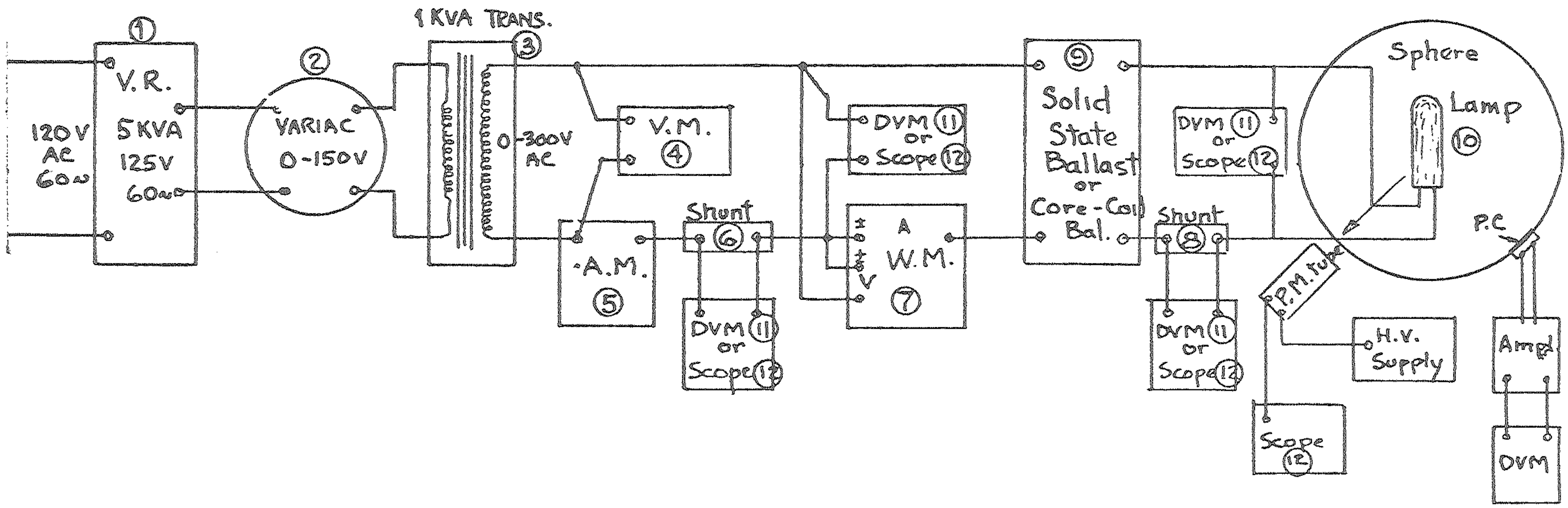
Procedure: With the circuit connected as shown, the voltage to the ballast was gradually increased until a starting current was observed. The voltage was then increased to the rated value, 277 volts. After a warm-up and stabilization period of at least 15 minutes, readings were made on the input and output parameters.

The solid state ballasts were individually adjusted by means of an external 500K potentiometer (factory provided) to deliver approximately 200W to the HPS lamp. The same lamp was used for all of the tests.

Voltmeter 4 and Ammeter 5 were used for initial set-up and to monitor the input conditions. The recorded values of input voltage and current were made using the Data Precision DVM 11 connected across the ballast input or across the shunt 6 .

The wattmeter 7 was connected to read only the power input to the ballast and load. A correction was made for the losses in the voltage winding of the wattmeter.

Circuit Diagram for tests on Solid State Ballasts



(1) **Voltage Regulator**
Sorensen AC Voltage Regulator
3KVA, 40A, 115 VAC
Ser. 2050

(2) **Variac**
Superior Powerstat
Type S649, 230V, 60n, 9A

(3) **1 KVA Transformer**
GE 76G 129, 1.0 KVA, 60n
Ser. 0J WJ

(4) **Voltmeter 1**
Sensitive Research
Mod.D, Ser. 800560
0-300 V, dyn. type

(5) **Ammeter 1**
Weston 370 Ser. 12329
0-1-2 amps, dyn. type

(6) **Shunt 1**
L&N 4385
on 1.5a position
10 x mv = amps

(7) **Wattmeter**
Weston 310 Ser. 16197
0-2A, 0-300V
0-50 scale, dyn. type

(8) **Shunt 2**
Weston 2A, 50 mv.

(9) **Solid State Ballast**
Luminoptic
Mod. 8661-01
(LBL prototype)
or
Core-Coil Ballast
ITT P33353/24349
200W, 277V

(10) **Lamp**
Westinghouse
Ceramalux HPS 200W
C200S66

(11) **DVM 1**
Data Precision
Mod. 2480R
True RMS - V&A

(12) **Tektronix #561 Oscilloscope**
with #63 differential
amplifier & #67 Time Base.
W/Beattie Polaroid Camera,
Mod. K5.

The output of the ballast was connected to the lamp using approximately 5 ft of wire. Voltage at the lamp was measured at the lamp socket using separate voltage leads brought out to the DVM (11) . The current was measured at shunt (8) using the DVM (11) .
Note: The output frequency of the solid state ballasts is approximately 27,000 cps. The Data Precision DVM was calibrated on 3/29/80 up to 20,000 cps with negligible error indicated. The errors at 27K Hz are not known, but since the wave shapes of voltage and current are approximately sinusoidal the meter readings have been used without correction. The DP meter measures TRUE RMS values.

The lamp wattage for the solid state ballasts was computed as the product of lamp volts times lamp current. This was permissible since the lamp current and voltage were approximately sinusoidal and the lamp acts like a pure resistance at the high frequency of 27K Hz.

After the ballast and lamp had reached stable operation at 277 volts input after about 15 minutes, the input and output parameters were measured. The input voltage was then changed to +10% (304.7) volts and then to -10% (249.3) volts. The input and output parameters were measured at each input voltage.

The light output was measured using a 48 inch integrating sphere with the 200W HPS lamp mounted at the center. A color corrected barrier layer photocell was used to measured the light flux in the sphere. The photocell, amplifier and read-out meter were calibrated using NBS reference standards (incandescent).

The light wave shape was measured using a photomultiplier tube looking at the HPS lamp. The tube was operated at 600V and the output was observed and photographed on a Tektronix 561 oscilloscope.

The lamp wattage for the core-coil ballast was measured with a dynamometer type wattmeter. The frequency is within the meter's range. The wave shapes are not sinusoidal and the phase angle was not known, so the volt x amperes calculation could not be used.

A test to simulate the change in electrical characteristics of the lamp with lamp life was made by heating the lamp. This was done by wrapping the lamp loosely with aluminum foil. The reflected radiation caused the lamp to heat which caused the arc voltage to increase and the input watts to increase up to a maximum and then to decrease. The plots of lamp watts vs lamp voltage are shown in the accompanying curves for the individual ballasts.

The same ballast performance effect was obtained by using various non-inductive resistance loads on the ballasts. One set of data for one ballast is shown on the curve sheet for ballast No. 002 for the ballast without the trim adjusting potentiometer.

Test Results

The test results are summarized in the tables and curves on the following pages.

Tests on HID Ballasts - for LBL

Ballast	Input Volts	Input Amps	Input Watts	Input Power Factor	Output Volts	Output Amps	Output Watts	Ballast Eff. (percent)	Lamp Output (lumens)	Lamp Efficacy l/w	Overall System Efficacy l/w	Flicker Index	Percent Flicker
Serial No. 000 Luminoptics LBL 8661-01 with 200 W - HPS - Westinghouse lamp	Rated 277.0	0.806	211.7	0.946	89.0	2.25	200.5	94.7	23531	117.4	111.2	0.002	0.8%
	+10% 304.9	0.744	215.7	0.951	89.6	2.25	201.3	93.7	23602	117.3	109.4		
	-10% 249.4	0.890	208.7	0.940	89.1	2.26	201.8	96.7	23285	115.4	111.6		
		Cold Start @ 190 - 200 volts.											
Serial No. 001 Luminoptics LBL 8669-01 with 200 W - HPS - Westinghouse lamp	Rated 277.2	0.830	219.7	0.955	90.0	2.24	201.9	91.9	22796	112.9	103.8	0.002	0.8%
	+10% 304.4	0.767	222.7	0.954	90.1	2.26	203.2	91.2	22995	113.2	103.3		
	-10% 249.3	0.922	215.7	0.939	89.9	2.25	202.2	93.7	22796	112.7	105.7		
		Cold Start @ 190 - 200 volts											

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Tests on HID Ballasts - for LBL

Ballast	Input Volts	Input Amps	Input Watts	Input Power Factor	Output Volts	Output Amps	Output Watts	Ballast Eff. (percent)	Lamp Output (lumens)	Lamp Efficacy l/w	Overall System Efficacy l/w	Flicker Index	Percent Flicker
Serial No. 002 Luminoptics LBL 8661-01 with 200 W - HPS - Westinghouse lamp	Rated 277.4	0.809	213.2	0.950	90.1	2.21	199.5	93.6	21700	108.8	101.8	0.002	0.8%
*	Rated 276.7	0.869	229.7	0.955	96.0	2.30	220.8	96.1	24415	110.6	106.3		
*	+10% 305.2	0.800	232.1	0.950	96.3	2.29	220.5	95.0	24536	111.3	105.7		
*	-10% 249.0	0.970	228.1	0.945	95.6	2.32	221.8	97.2	24293	109.5	106.5		
	* ballast not trimmed to 200 watts to lamp (as received w/o 500 K trim pot) Cold Start @ 190 - 200 volts.												
Serial No. 004 Luminoptics LBL 8661-01 with 200 W - HPS - Westinghouse lamp	Rated 277.3	0.813	225.4	0.964	89.2	2.28	203.2	93.6	22070	108.6	97.9	0.002	0.8%
	+10% 304.8	0.751	219.2	0.958	89.8	2.25	202.0	92.2	22035	109.1	100.5		
	-10% 249.1	0.910	214.2	0.945	89.9	2.26	202.8	94.7	21736	107.2	101.5		
	Cold Start @ 190 - 200 volts.												

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Tests on HID Ballasts - for LBL

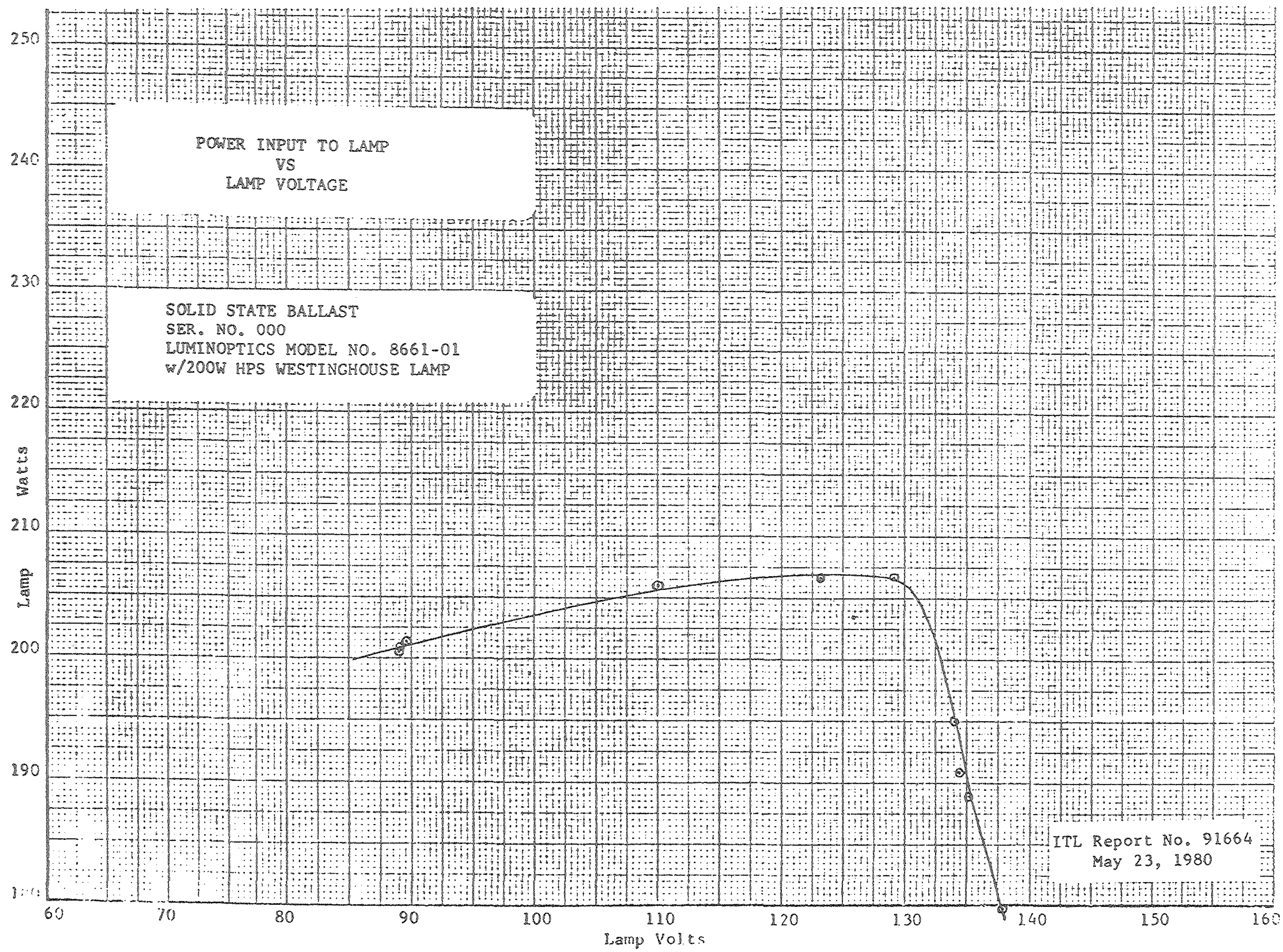
Ballast	Input Volts	Input Amps	Input Watts	Input Power Factor	Output Volts	Output Amps	Output Watts	Ballast Eff. (percent)	Lamp Output (lumens)	Lamp Efficacy l/w	Overall System Efficacy l/w	Flicker Index	Percent Flicker
Serial No. 005 Luminoptics LBL 8661-01 with 200 W - HPS - Westinghouse lamp	Rated 277.2	0.784	208.9	0.961	88.6	2.26	200.6	96.0	21266	105.8	101.6	0.002	0.8%
	+10% 304.8	0.754	212.7	0.926	88.8	2.25	199.6	93.6	21524	107.8	101.2		
	-10% 249.1	0.891	207.7	0.936	88.6	2.27	200.9	96.7	21260	105.8	102.4		
		Cold	Start @	190 - 200 volts.									
Serial No. 007 Luminoptics LBL 8661-01 with 200 W - HPS - Westinghouse lamp	Rated 277.3	0.801	213.2	0.960	89.3	2.24	200.2	93.9	21208	105.9	99.5	0.002	0.8%
	+10% 304.9	0.743	216.7	0.957	89.3	2.29	204.4	94.3	21507	105.2	99.2		
	-10% 249.2	0.889	210.2	0.949	89.0	2.28	203.2	96.7	21243	104.5	101.1		
		Cold	Start @	190 -	200 volts.								

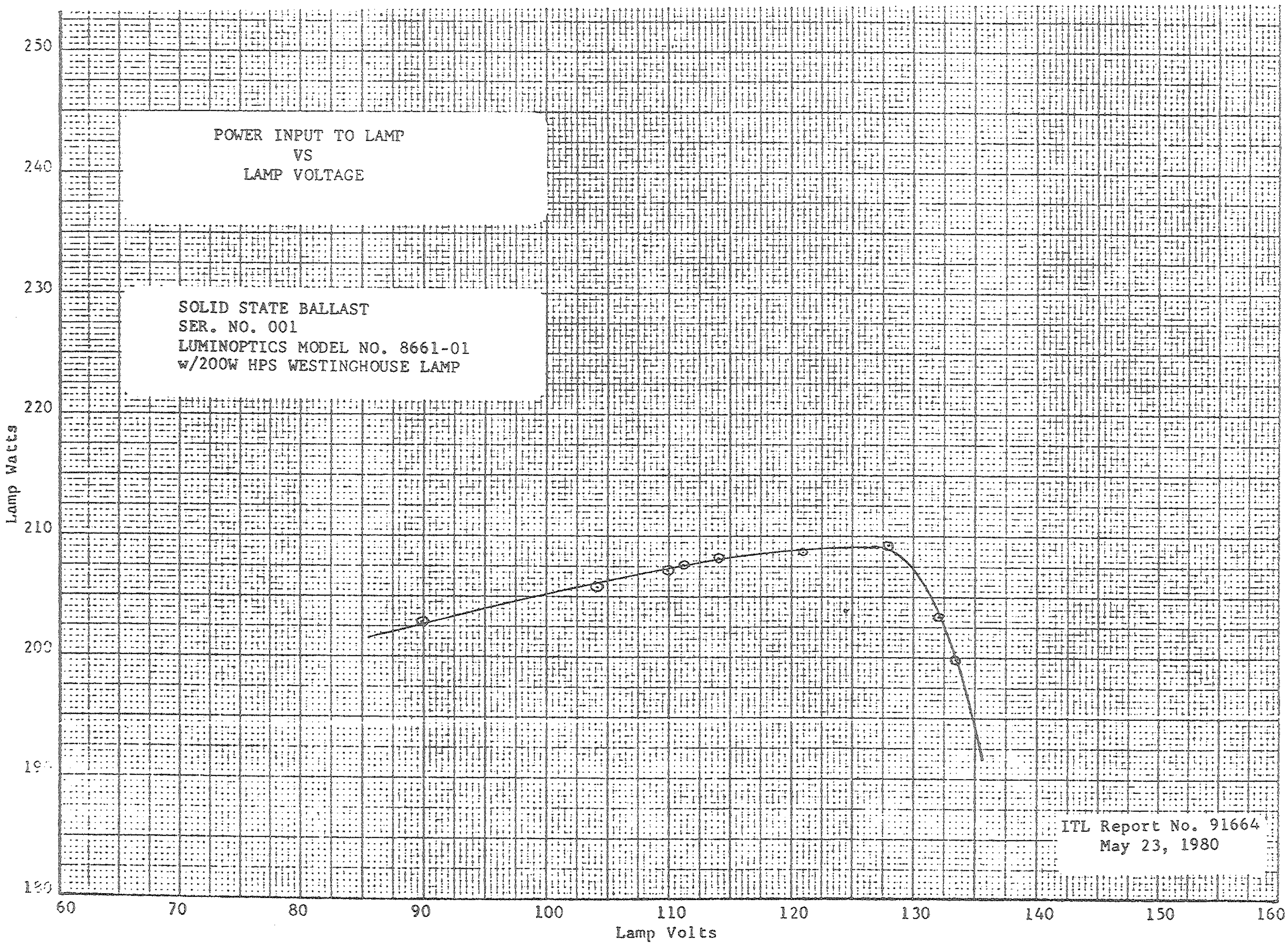
ITL Test Report 91664

Tests on HID Ballasts - for LBL

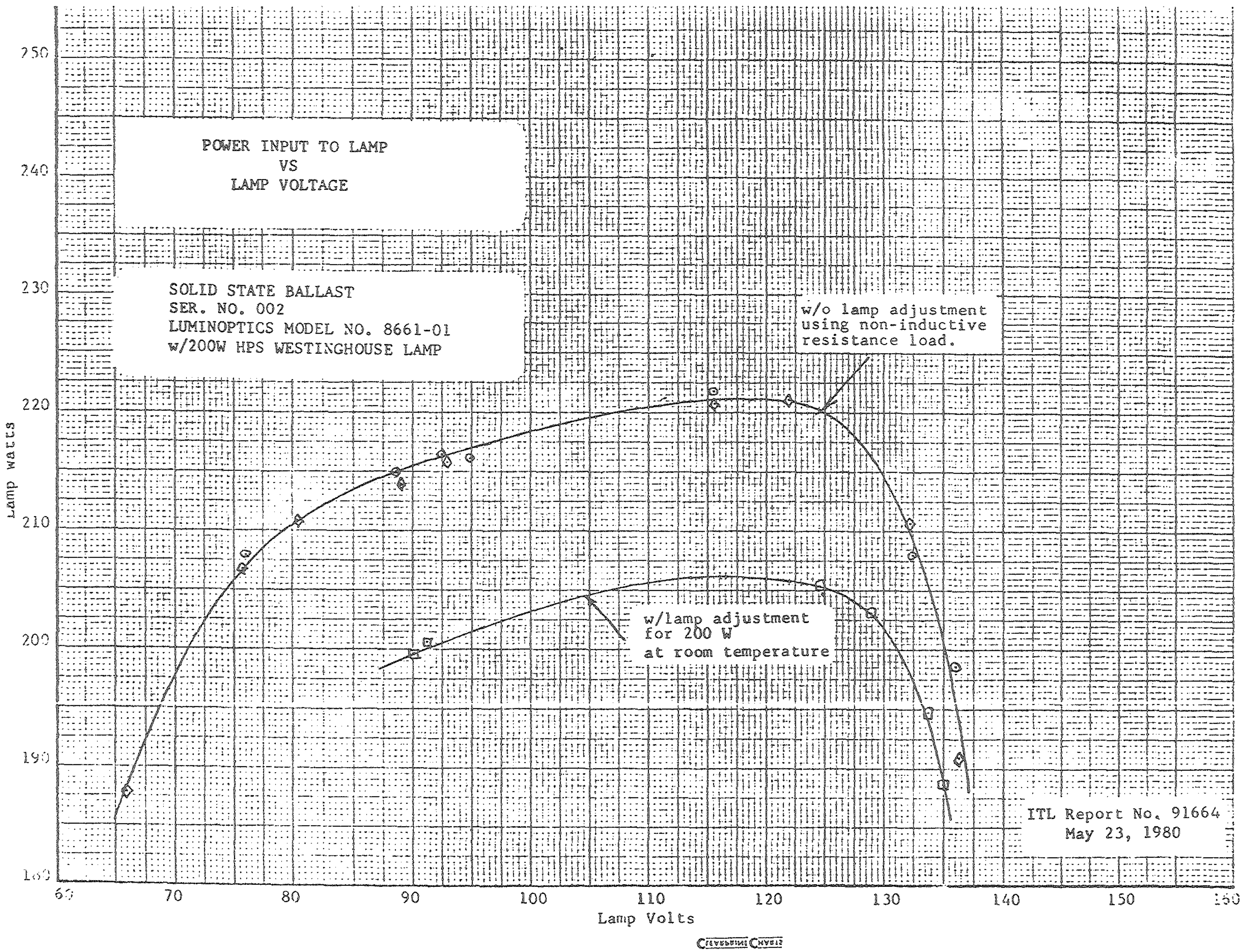
Ballast	Input Volts	Input Amps	Input Watts	Input Power Factor	Output Volts	Output Amps	Output Watts	Ballast Eff. (percent)	Lamp Output (lumens)	Lamp Efficacy l/w	Overall System Efficacy l/w	Flicker Index	Percent Flicker
Core-Coil Reference Ballast Luminoptics LBL 8661-01 with 200 W - HPS - Westinghouse lamp	Rated 277.2	0.971	261.7	0.973	101.4	2.36	201.8	77.1	21483	106.5	82.1	0.063	12.1%
	+10% 304.5	0.998	288.8	0.950	109.7	2.40	221.7	76.8	23951	108.0	82.9		
	-10% 250.0	0.936	223.2	0.953	88.3	2.30	171.0	76.6	17963	105.0	80.5		
		Cold	Start	- beginning @ 80 volts. - steady on @ 100 volts.									

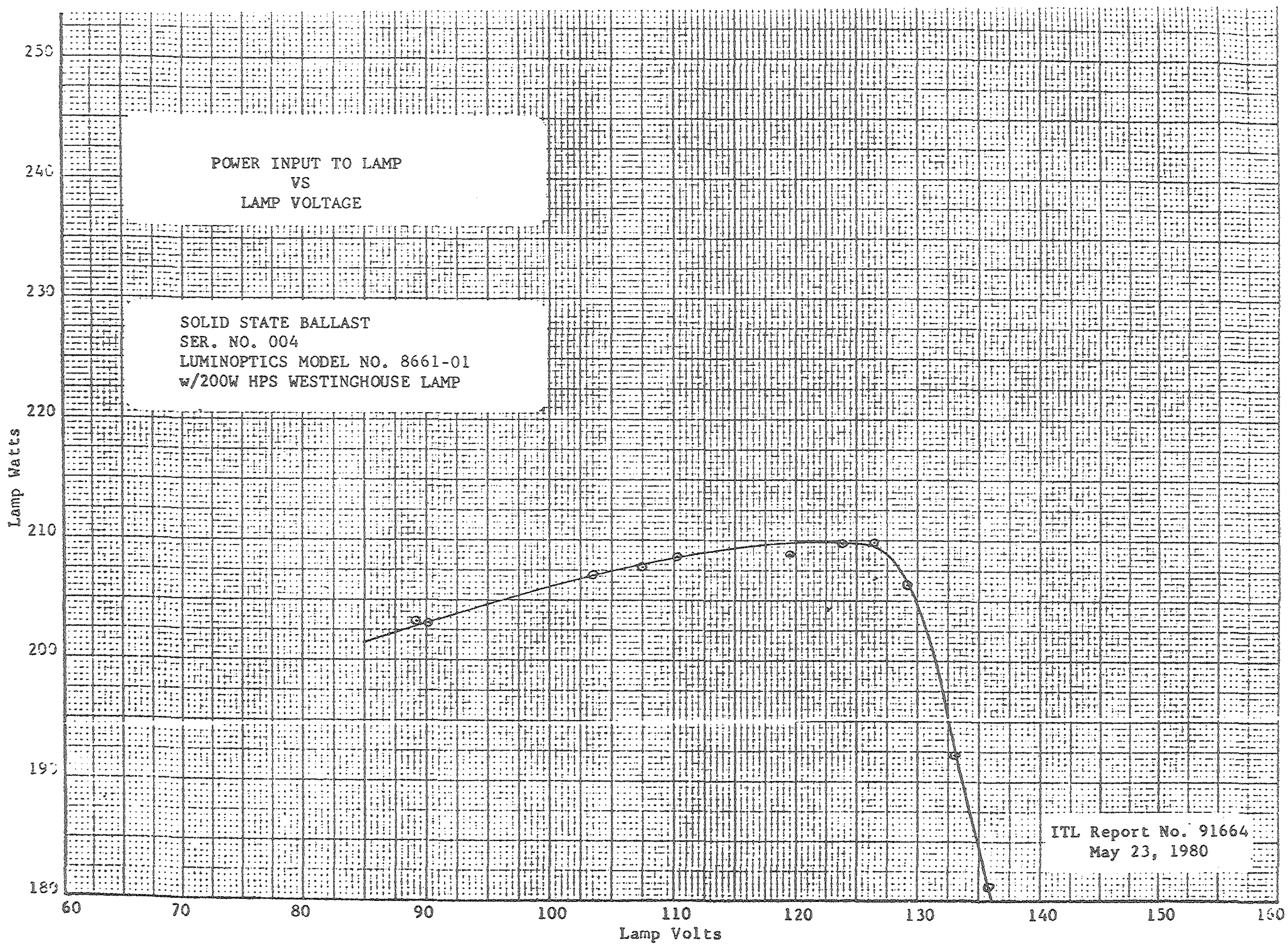
ITL Test Report 91664

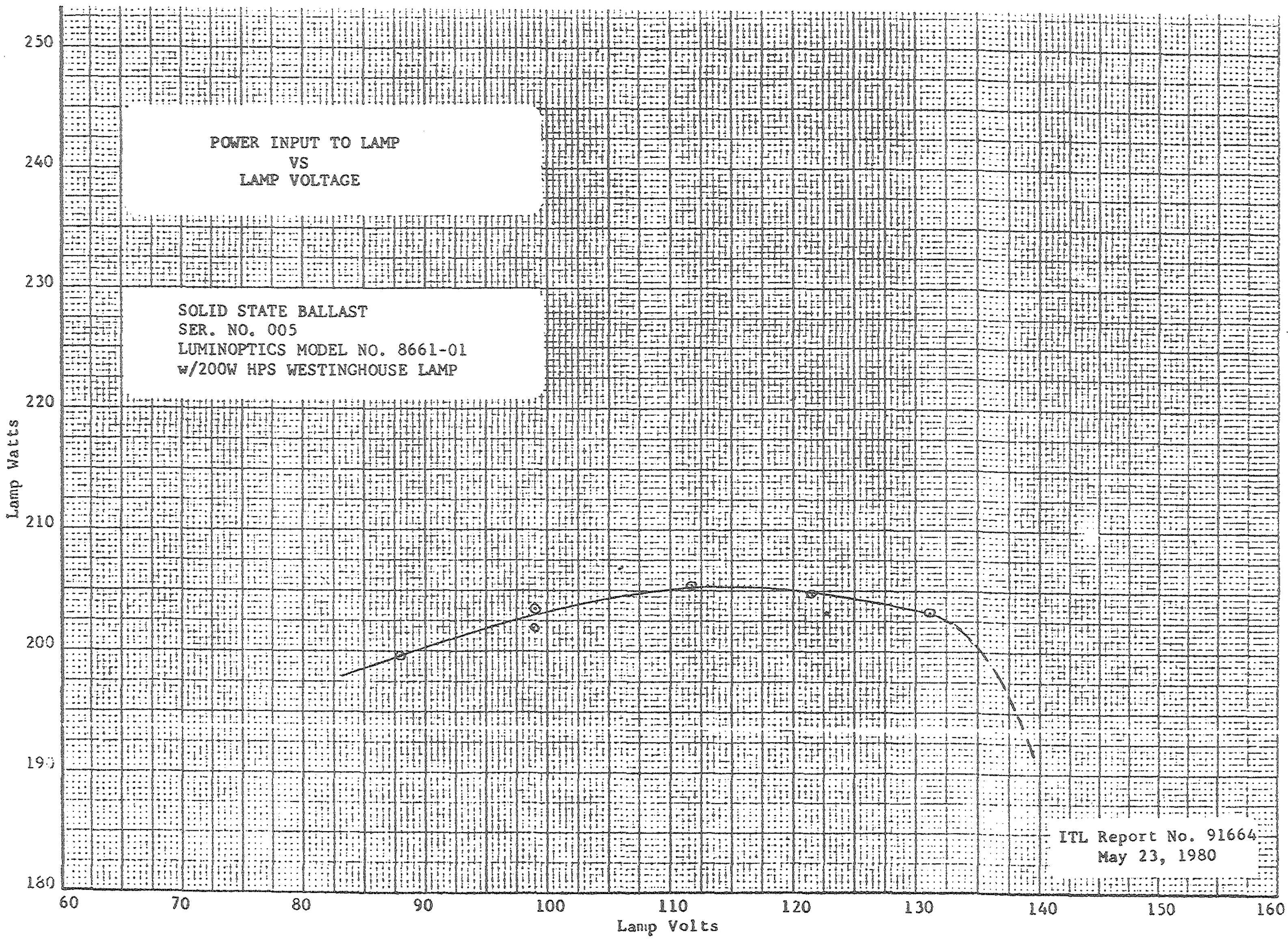

POWER INPUT TO LAMP
VS
LAMP VOLTAGE
SOLID STATE BALLAST
SER. NO. 000
LUMINOPTICS MODEL NO. 8661-01
w/200W HPS WESTINGHOUSE LAMP
ITL Report No. 91664
May 23, 1980
Lamp Watts
Lamp Volts
250
240
230
220
210
200
190
60
70
80
90
100
110
120
130
140
150
160
CLEARPRINT CHARTS

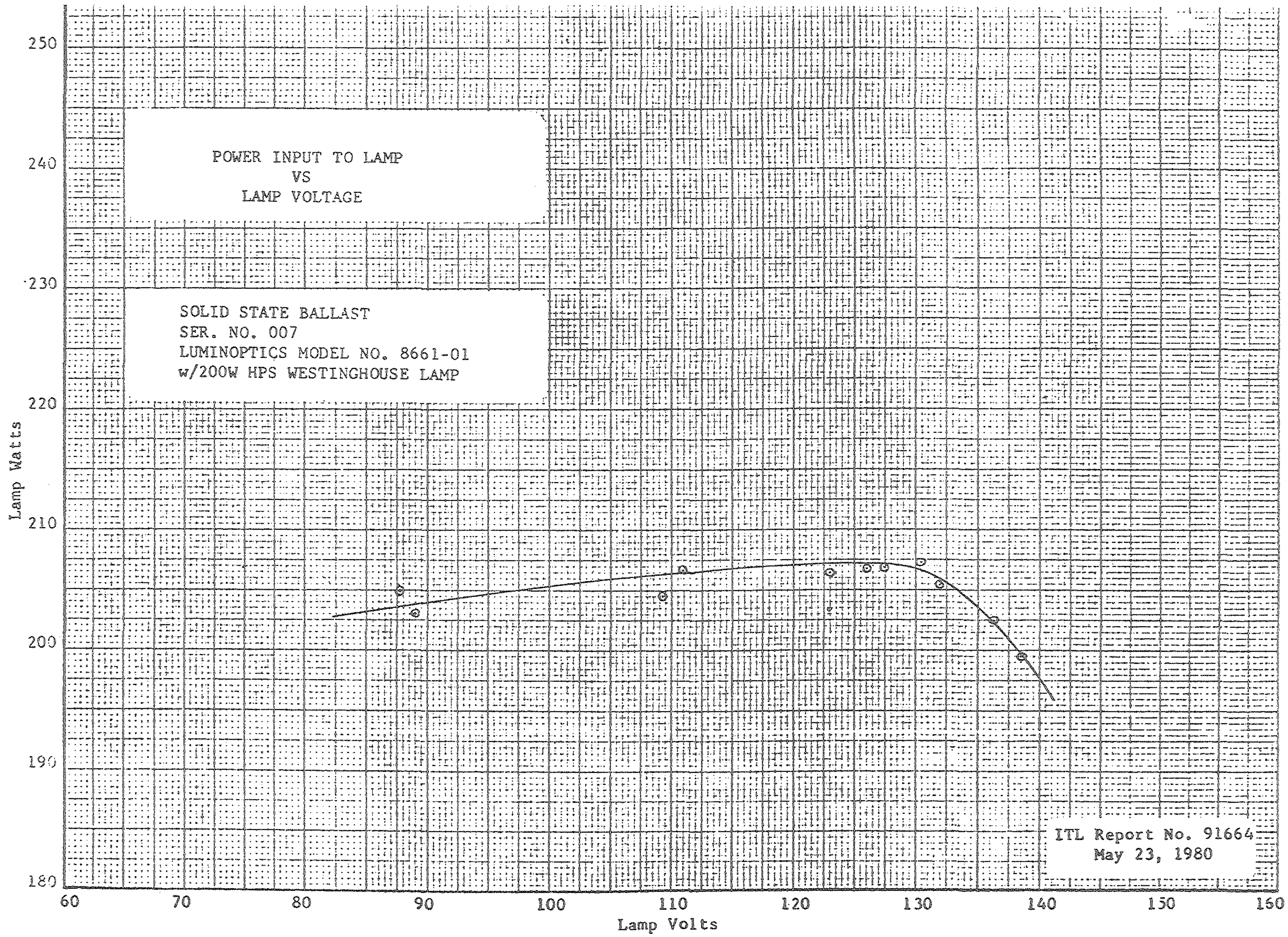


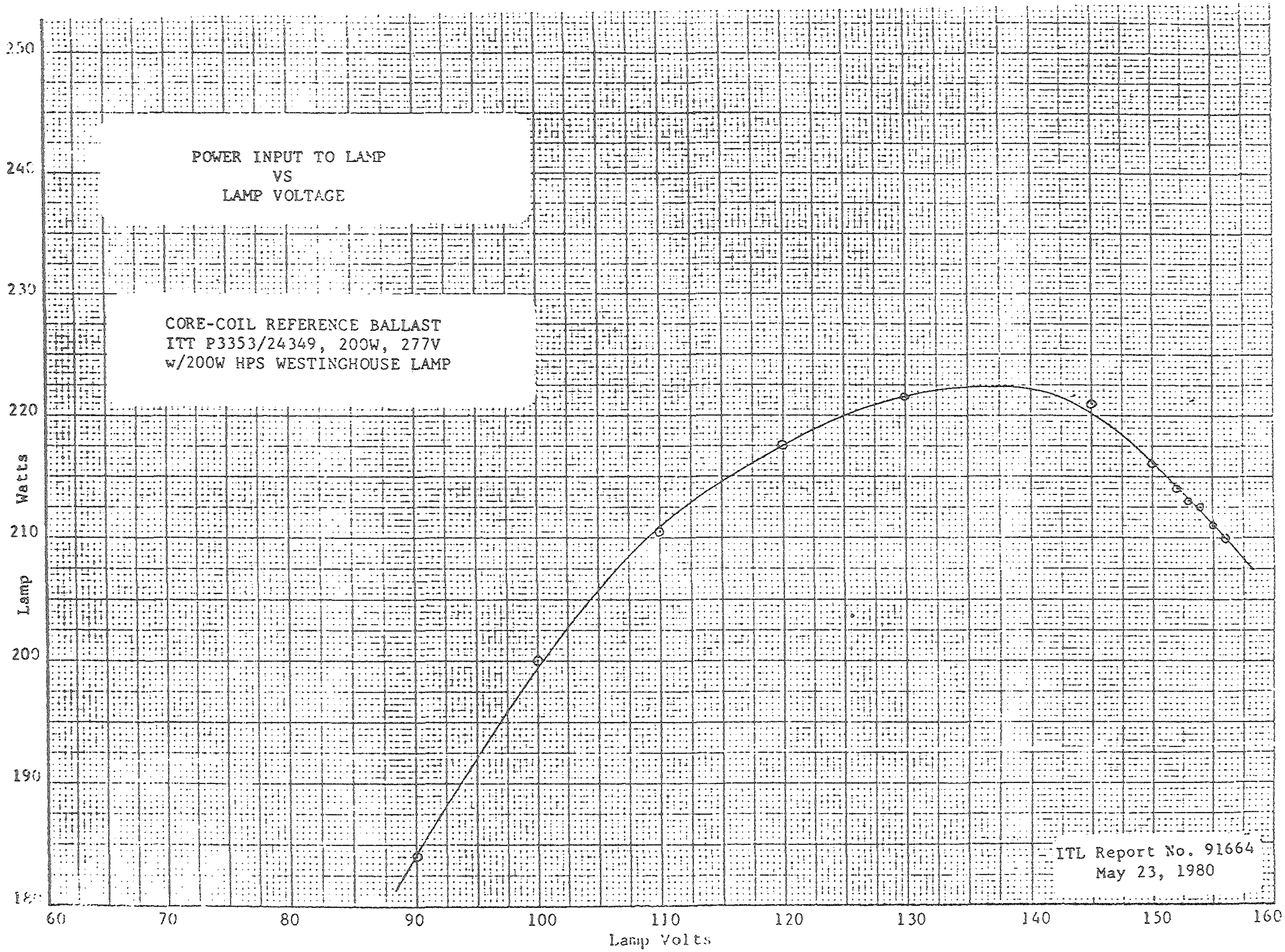
POWER INPUT TO LAMP
VS
LAMP VOLTAGE
SOLID STATE BALLAST
SER. NO. 001
LUMINOPTICS MODEL NO. 8661-01
w/200W HPS WESTINGHOUSE LAMP
ITL Report No. 91664
May 23, 1980
Lamp Watts
250
240
230
220
210
200
180
Lamp Volts
60
70
80
90
100
110
120
130
140
150
160


POWER INPUT TO LAMP
VS
LAMP VOLTAGE
SOLID STATE BALLAST
SER. NO. 002
LUMINOPTICS MODEL NO. 8661-01
w/200W HPS WESTINGHOUSE LAMP
w/o lamp adjustment
using non-inductive
resistance load.
w/lamp adjustment
for 200 W
at room temperature
ITL Report No. 91664
May 23, 1980
Lamp watts
Lamp Volts
250
240
230
220
210
200
190
70
80
90
100
110
120
130
140
150


POWER INPUT TO LAMP
VS
LAMP VOLTAGE
SOLID STATE BALLAST
SER. NO. 004
LUMINOPTICS MODEL NO. 8661-01
w/200W HPS WESTINGHOUSE LAMP
ITL Report No. 91664
May 23, 1980
Lamp Watts
180
190
200
210
220
230
240
250
Lamp Volts
60
70
80
90
100
110
120
130
140
150
160


POWER INPUT TO LAMP
VS
LAMP VOLTAGE
SOLID STATE BALLAST
SER. NO. 005
LUMINOPTICS MODEL NO. 8661-01
w/200W HPS WESTINGHOUSE LAMP
ITL Report No. 91664
May 23, 1980
Lamp Watts
Lamp Volts
250
240
230
220
210
200
180
60
70
80
90
100
110
120
130
140
150
160


POWER INPUT TO LAMP
VS
LAMP VOLTAGE
SOLID STATE BALLAST
SER. NO. 007
LUMINOPTICS MODEL NO. 8661-01
w/200W HPS WESTINGHOUSE LAMP
ITL Report No. 91664
May 23, 1980
Lamp Watts
250
240
230
220
210
200
190
180
60
70
80
90
100
110
120
130
140
150
160
Lamp Volts


POWER INPUT TO LAMP
VS
LAMP VOLTAGE
CORE-COIL REFERENCE BALLAST
ITT P3353/24349, 200W, 277V
w/200W HPS WESTINGHOUSE LAMP
ITL Report No. 91664
May 23, 1980
Lamp Watts
Lamp Volts
250
240
230
220
210
200
190
60
70
80
90
100
110
120
130
140
150
160

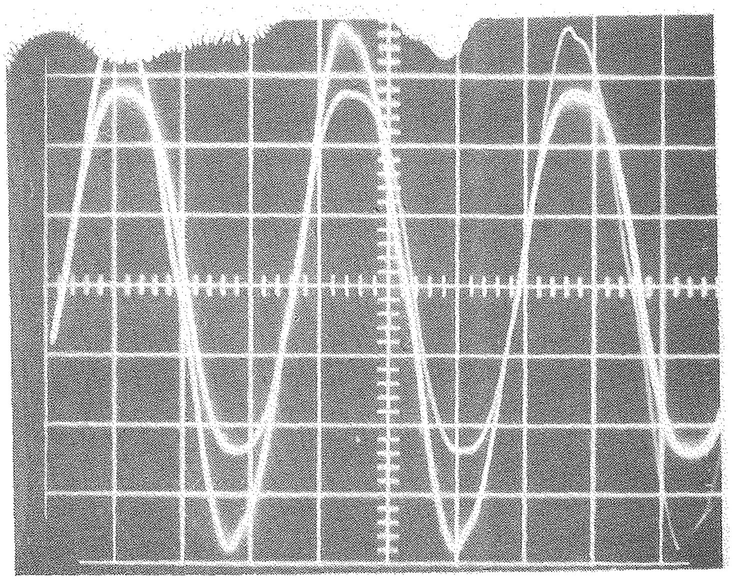
Wave Shapes - Current, Voltage, Light

The wave shapes of the input and output current and voltage are shown on the photographs of the traces on the oscilloscope. Both current and voltage are shown on the same photograph. However, the phase relationship should not be inferred since the scope is a single trace instrument. When the input was switched from current to voltage the trigger pulse was the same for each, so the starting time on the scope in each cycle was not necessarily the synchronus time for the two quantities. The shape of each wave is correctly shown.

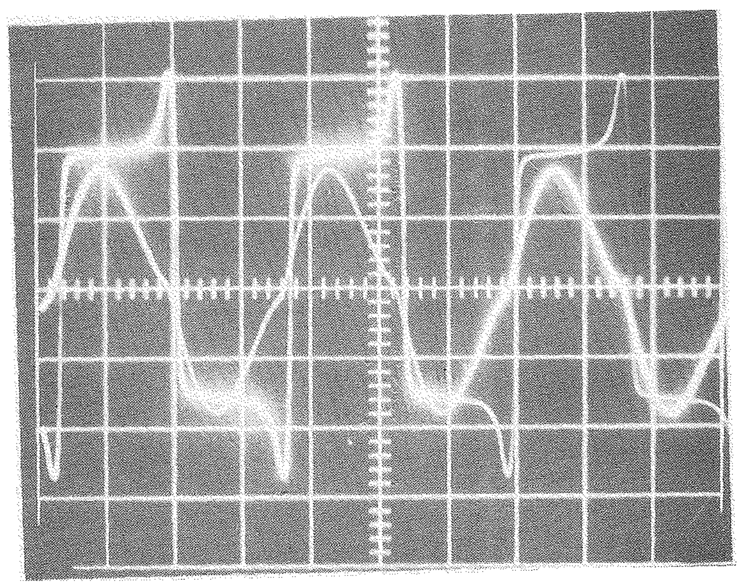
The wave shape of the light output is shown to an amplified value in order to show its AC component. The AC is superimposed upon a large DC component. Thus, for the solid state ballasts, the flicker index and percent flicker are essentially zero. Also since the flicker is at approximately 54K Hz, there is no visual effect. The reference core-coil ballast does exhibit more flicker than the solid state ballasts. It is at 120 Hz and is nominal in magnitude so its visual effect is also small.(not noticeable).

Input and Output -- Current, Voltage, Light -- Wave Shapes

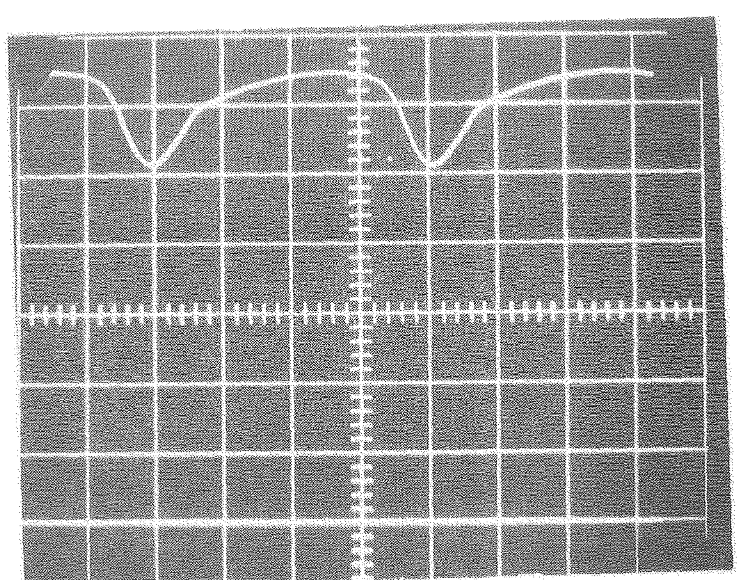
Core-Coil Reference ITT
ITT American Electric
P33353/24349. 200 W, 277 V



Input voltage 277 volts RMS
(high peak) 60 Hz
Input current 0.971 amps RMS
(low peak) 60 Hz



Output voltage 101.4 V RMS
(high peak) 27000 Hz
Output current 2.36 a RMS
(low peak) 27000 Hz



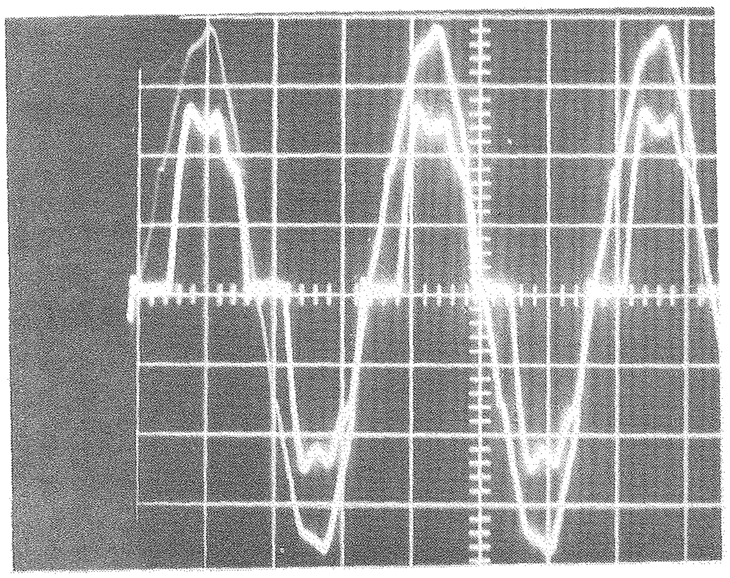
Lamp output wave shape
AC component at 5mv/div.
DC component = 6.3 div @ 20 V/div.
Flicker index ≅ 0.063

XBB 811-1064

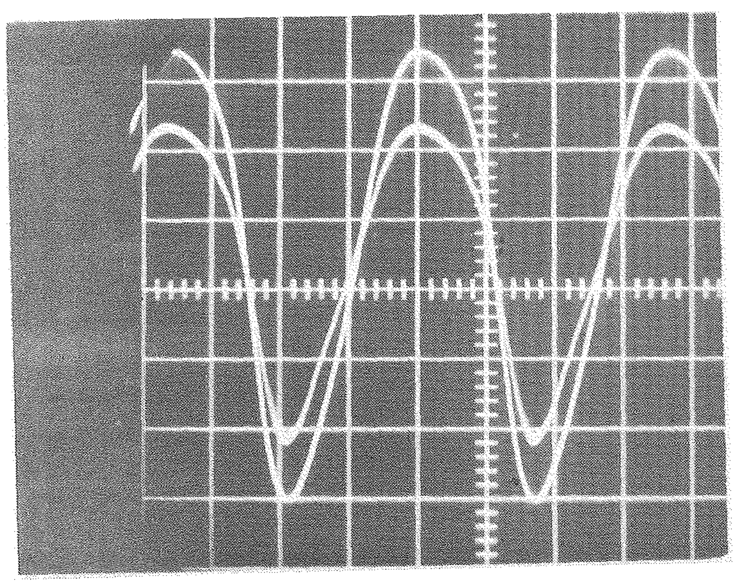
ITL Report No. 91664
Date: May 21, 1980

Input and Output -- Current, Voltage, Light -- Wave Shapes

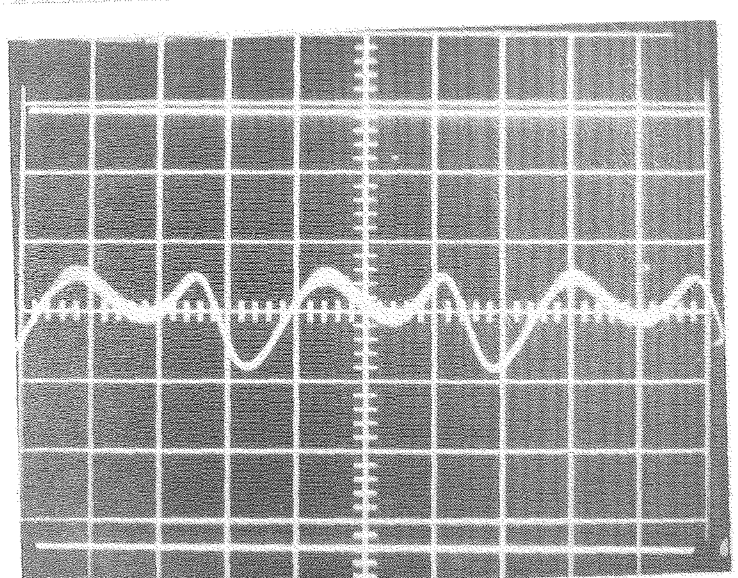
Ballast Serial No. 000
Luminoptics Model 8661-01
w/200 W HPS Westinghouse lamp



Input voltage 277 volts RMS
(high peak) 60 Hz
Input current 0.806 amps RMS
(flat at 0) 60 Hz



Output voltage 89.0 V RMS
(high peak) 27000 Hz
Output current 2.25 a RMS
(low peak) 27000 Hz



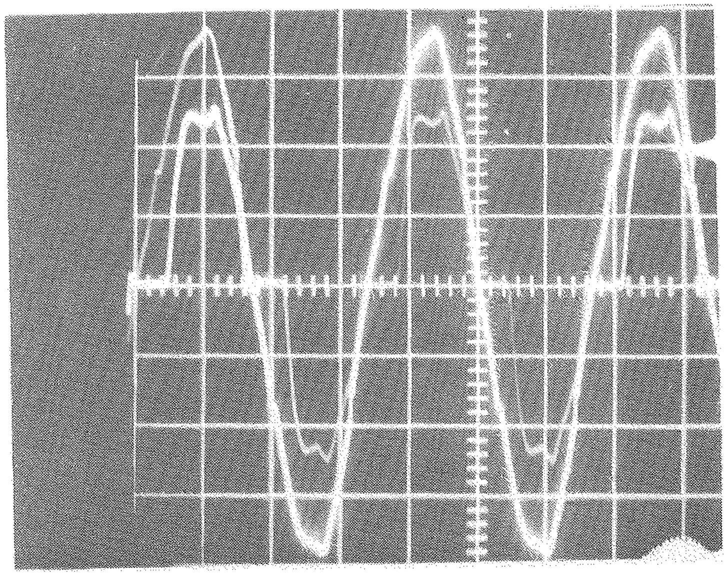
Lamp output wave shape
AC component at 5mv/div.
DC component = 6.3 div @ 20 V/div.
Flicker index ≅ 0.002

ITL Report No. 91664
Date: May 21, 1980

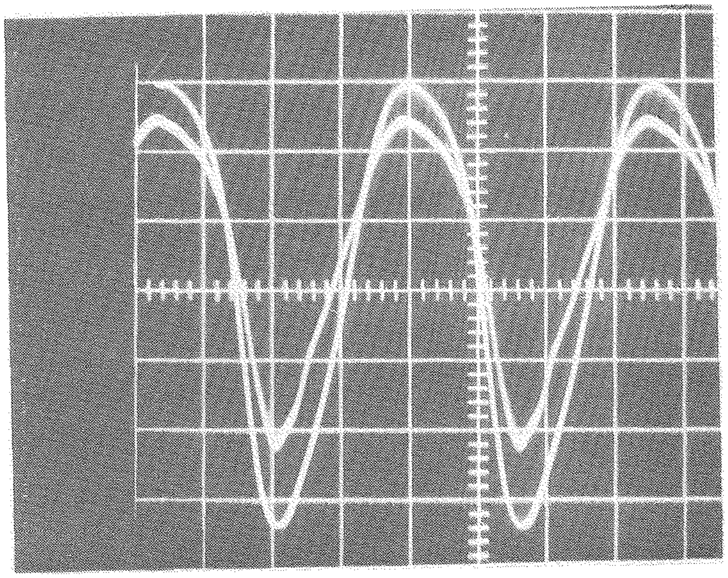
XBB 811-1065

Input and Output -- Current, Voltage, Light -- Wave Shapes

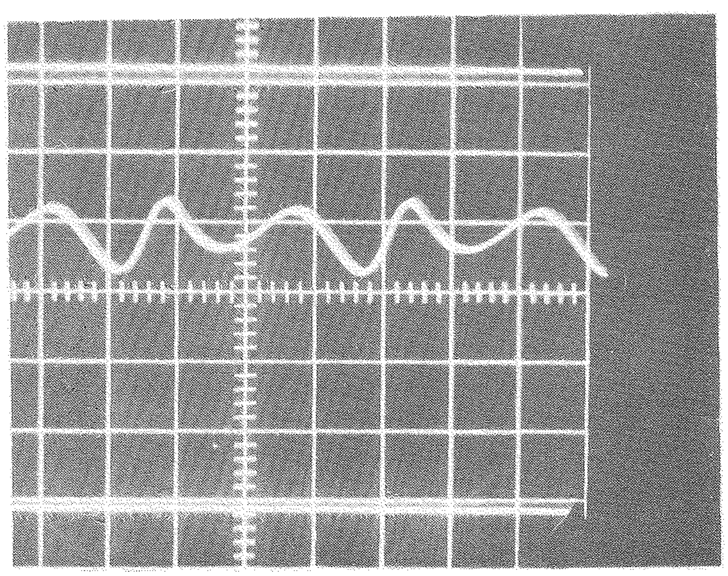
Ballast Serial No. 001
Luminoptics Model 8661-01
w/200 W HPS Westinghouse lamp



Input voltage	277 volts RMS
(high peak)	60 Hz
Input current	0.830 amps RMS
(flat at 0)	60 Hz



Output voltage	90.0 V RMS
(high peak)	27000 Hz
Output current	2.24 a RMS
(low peak)	27000 Hz



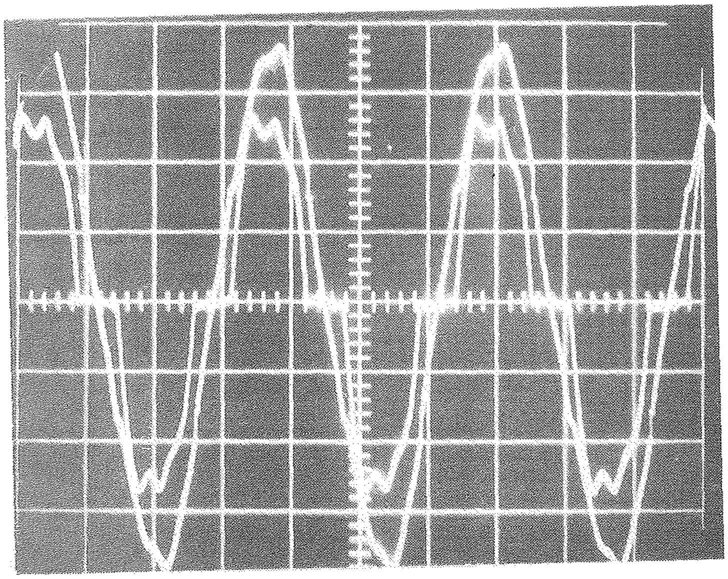
Lamp output wave shape
AC component at 5mv/div.
DC component = 6.3 div @ 20 V/div.
Flicker index ≅ 0.002

ITL Report No. 91664
Date: May 21, 1980

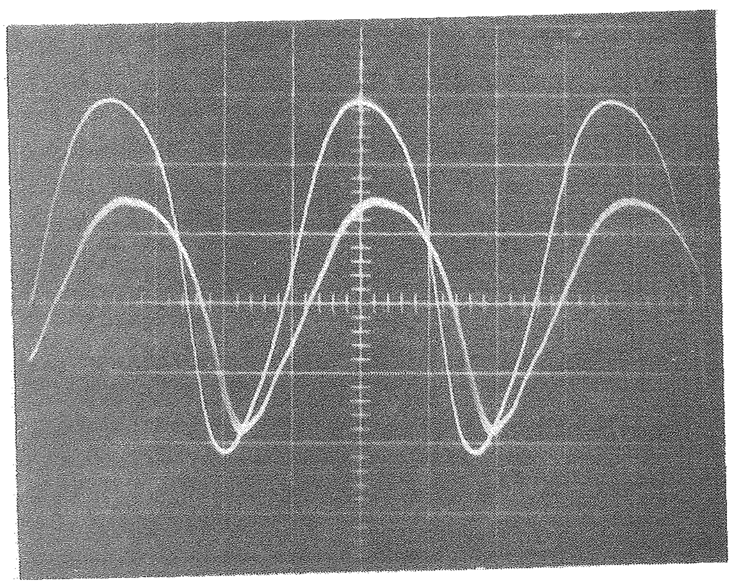
XBB 811-1066

Input and Output -- Current, Voltage, Light -- Wave Shapes

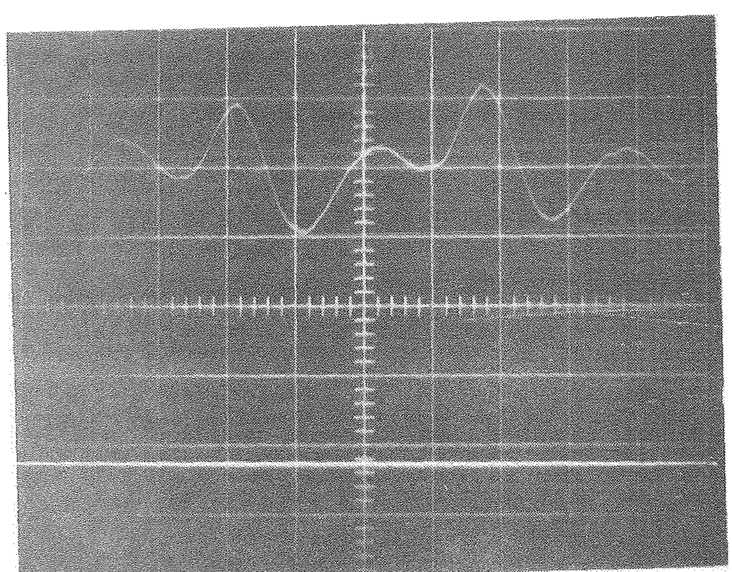
Ballast Serial No. 002
Luminoptics Model 8661-01
w/200 W HPS Westinghouse lamp



Input voltage	277 volts RMS
(high peak)	60 Hz
Input current	0.809 amps RMS
(flat at 0)	60 Hz



Output voltage	90.1 V RMS
(high peak)	27000 Hz
Output current	2.21 a RMS
(low peak)	27000 Hz



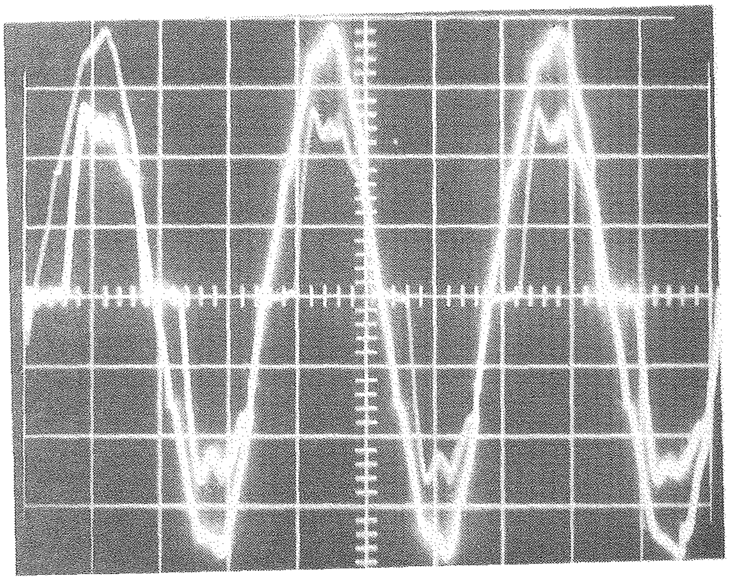
Lamp output wave shape
AC component at 5mv/div.
DC component = 6.3 div @ 20 V/div.
Flicker index ≅ 0.002

ITL Report No. 91664
Date: May 21, 1980

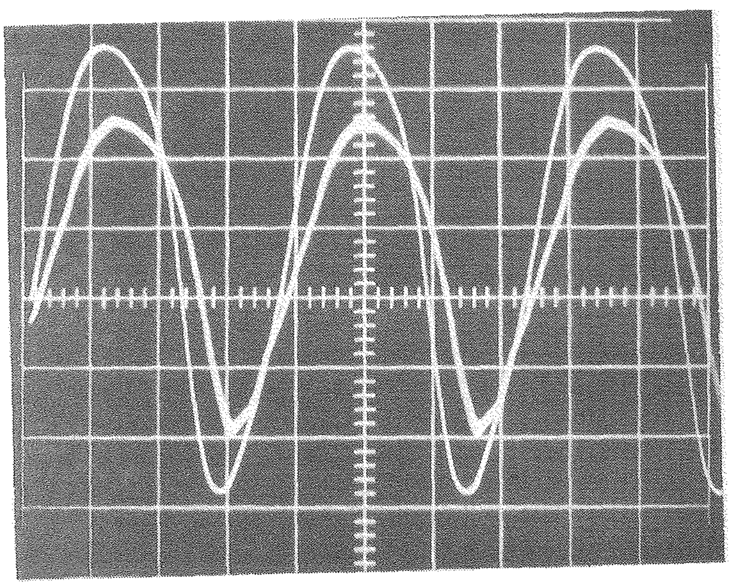
XBB 811-1067

Input and Output -- Current, Voltage, Light -- Wave Shapes

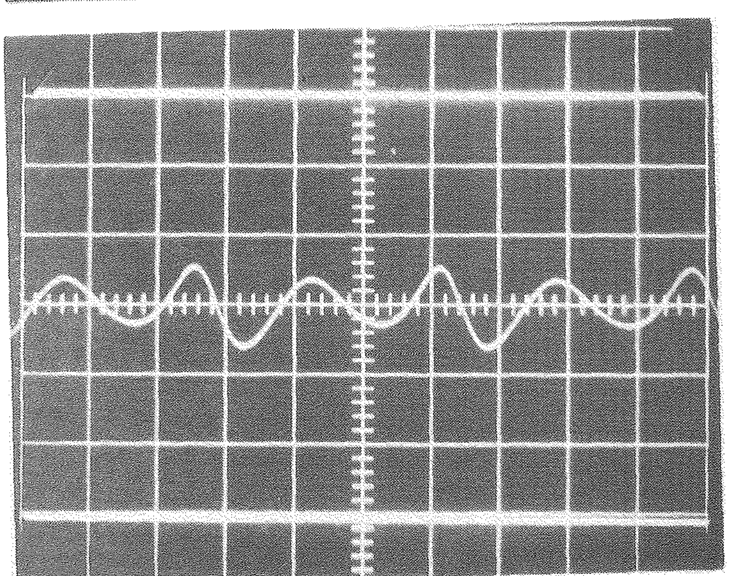
Ballast Serial No. 004
Luminoptics Model 8661-01
w/200 W HPS Westinghouse lamp



Input voltage	277 volts RMS
(high peak)	60 Hz
Input current	0.813 amps RMS
(flat at 0)	60 Hz



Output voltage	89.2 V RMS
(high peak)	27000 Hz
Output current	2.28 a RMS
(low peak)	27000 Hz



Lamp output wave shape

AC component at 5mv/div.

DC component = 6.3 div @ 20 V/div.

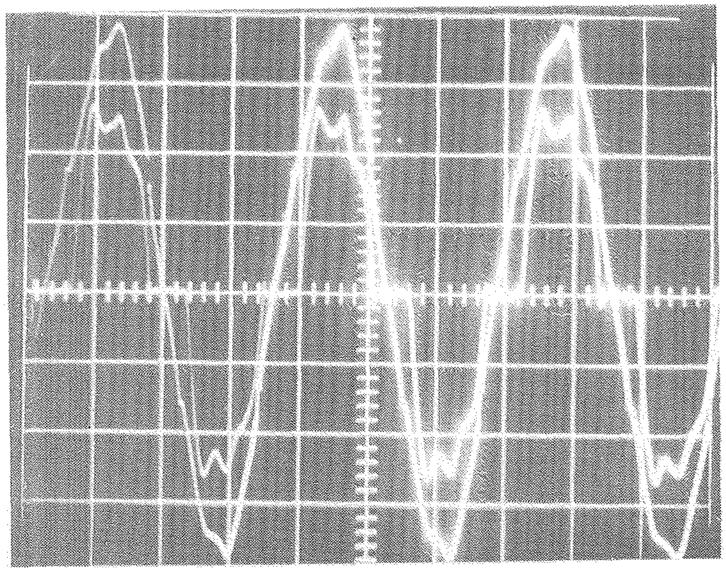
Flicker index $\cong$ 0.002

ITL Report No. 91664
Date: May 21, 1980

XBB 811-1068

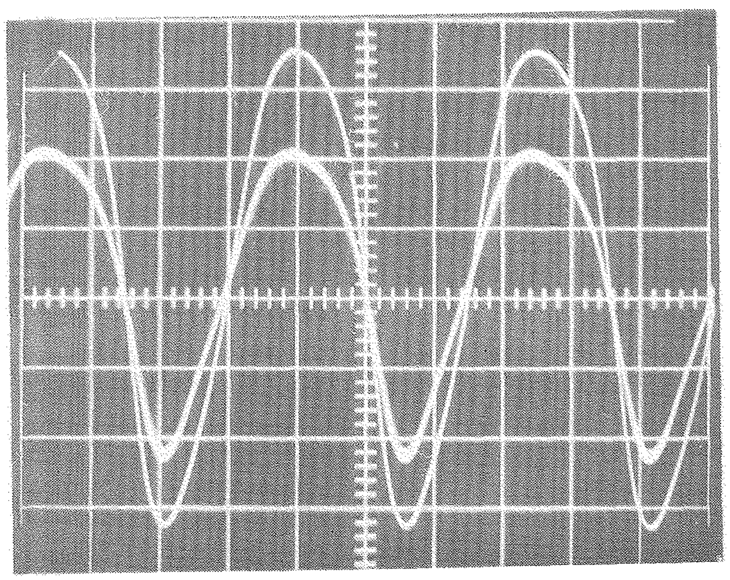
Input and Output -- Current, Voltage, Light -- Wave Shapes

Ballast Serial No. 005
Luminoptics Model 8661-01
w/200 W HPS Westinghouse lamp



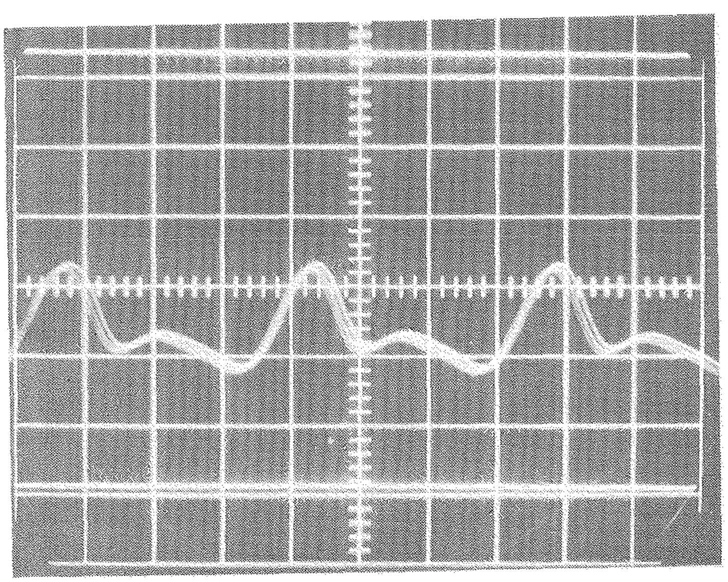
Input voltage (high peak) 277 volts RMS 60 Hz

Input current (flat at 0) 0.784 amps RMS 60 Hz



Output voltage (high peak) 88.6 V RMS 27000 Hz

Output current (low peak) 2.26 a RMS 27000 Hz



Lamp output wave shape

AC component at 5mv/div.

DC component = 6.3 div @ 20 V/div.

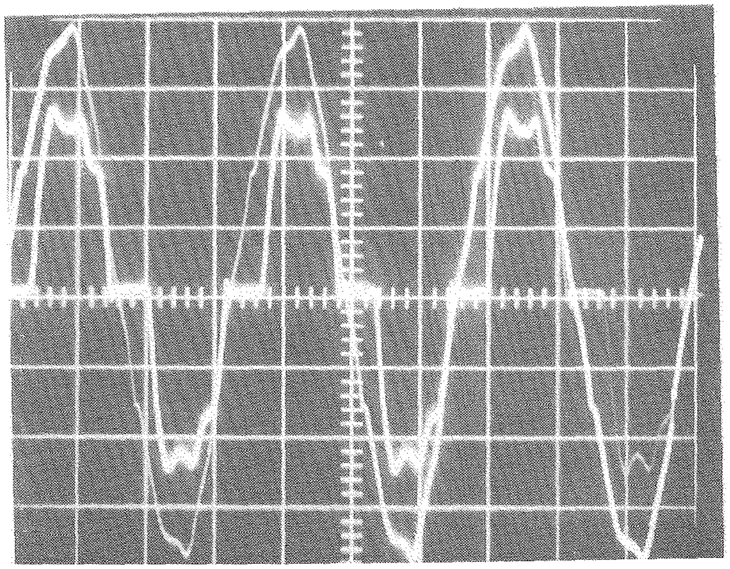
Flicker index ≅ 0.002

ITL Report No. 91664
Date: May 21, 1980

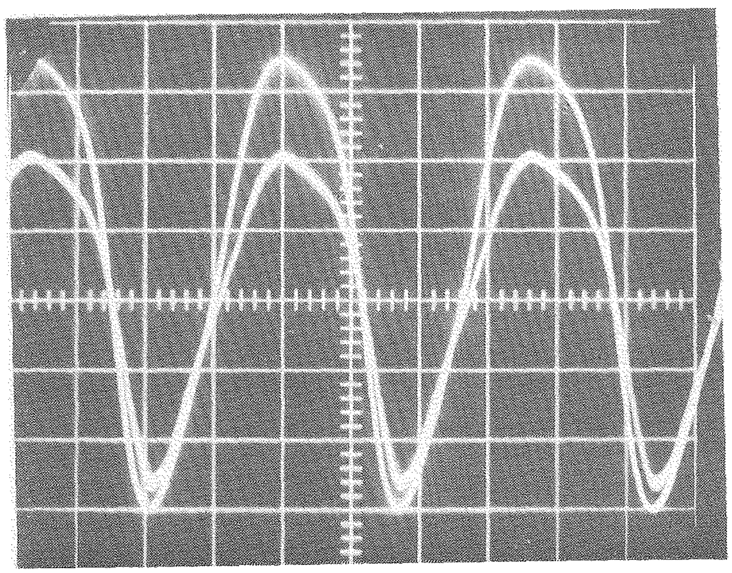
XBB 811-1069

Input and Output -- Current, Voltage, Light -- Wave Shapes

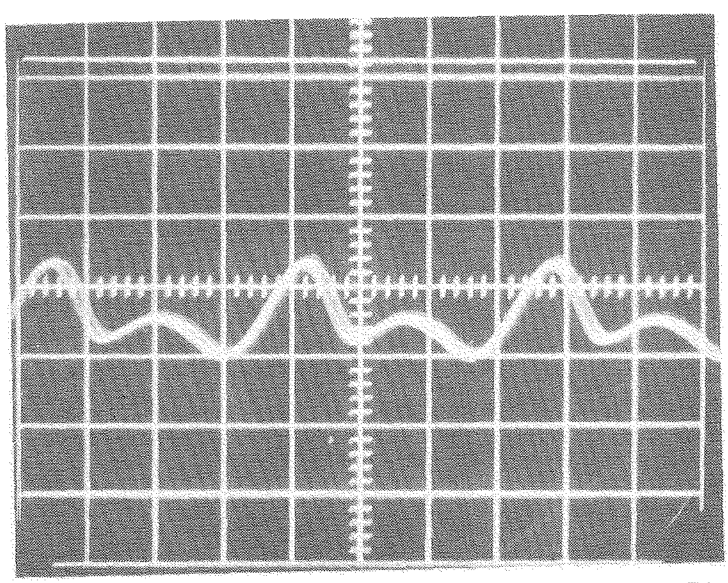
Ballast Serial No. 007
Luminoptics Model 8661-01
w/200 W HPS Westinghouse lamp



Input voltage	277 volts RMS
(high peak)	60 Hz
Input current	0.801 amps RMS
(flat at 0)	60 Hz



Output voltage	89.3 V RMS
(high peak)	27000 Hz
Output current	2.24 a RMS
(low peak)	27000 Hz



Lamp output wave shape

AC component at 5mv/div.

DC component = 6.3 div @ 20 V/div.

Flicker index ≅ 0.002

ITL Report No. 91664
Date: May 21, 1980

XBB 811-1070

Discussion and Comments

Solid State Ballasts

1. The input power and output power to the lamp show a high efficiency for the ballasts tested - On the order of 95%.

2. The power factor for the input current and voltage was high - On the order of 0.96. The wave shape for the input current has a flat spot as the current approaches zero. The latter does not reduce the power factor appreciably. Apparently the fundamental of the current and voltage wave shapes are almost in phase.

3. The high frequency output to the lamp causes the lamp to act like a pure resistance. The current and voltage wave shapes are approximately sinusoidal and are in phase. (Note: Our oscilloscope traces do not prove that they are in phase because a single beam CRS was used.)

4. The frequency of the light output is so high and the variation in light output is so small that there is no noticeable flicker to the light (flicker index = 0.002).

5. No problem was experienced with cold starting. All of the devices started the lamp at between 190 to 200 volts (ballast rated 277 volts). One ballast would not start the lamp in the "as received" condition. This ballast was exchanged by the manufacturer. The exchanged ballast performed satisfactorily. Information received later from the manufacturer indicated that a broken wire was found. After repair, the ballast operated satisfactorily.

6. The tests to determine the change in watts to the lamp with lamp life indicate an increase in wattage with increasing lamp voltage from $\approx$ 90 volts initial to $\approx$ 130 volts max. Then the watts to the lamp drop off and return to the initial value at $\approx$ 130 to 135 volts. Beyond this value of lamp voltage, the wattage drops off very rapidly. In service the lamp would probably fail to start. The total increase in lamp watts from the initial to max. value was approx. 2% to 3.5%.

Core-Coil Ballasts

7. The reference ballast (60 Hz input and output) was less efficient than the solid state ballasts tested, viz., 77%.

8. The power factor of the ballast was comparable to that of the solid state ballasts, viz., 0.95.

9. The 60 Hz output to the lamp and the resulting non-sinusoidal current and voltage to the lamp caused the flicker index and the percent flicker to be higher than for the solid state ballasts. For visual uses that do not involve stroboscopic effects, the flicker index would not be too high. However, if rotating or moving objects are viewed, there may be objectionable flicker effects. The flicker index equals 0.06.

10. No problem was found with cold starting. The lamp would begin to start at a voltage as low as 80 volts input and would cause steady operation at 100 to 120 volts input. Full output was obtained with 277 volts input.

11. The tests to determine the change in watts to the lamp with lamp life indicate an increase in wattage with increased lamp voltage up to about 144 volts. Beyond that time in the life of the lamp, the watts decrease until the ballast fails to start and maintain the lamp current. The lamp watts increased approximately 11% from the rated value (200W) to maximum value (222W).

DMFinch

INDUSTRIAL TESTING LABORATORIES

APPENDIX B

PRELIMINARY

INSTALLATION AND OPERATING INSTRUCTIONS

8661 SERIES 200 WATT HPS BALLAST

GENERAL: The 8661 high frequency electronic lamp ballast is designed to operate standard commercially available 200 watt high pressure sodium lamps either high output or color improved. The ballast is experimental and is designed to replace the core-coil ballast. The electronic ballast contains a built-in striker circuit for starting the lamps. When utilizing the electronic ballast, a starting capacitor is not required for power factor correction.

The 8661 Series ballast was designed to meet Stage I requirements for a three (3) stage testing program undertaken by Lawrence Berkeley Laboratories described as follows:

STAGE I - Develop a solid state high frequency ballast in limited prototypical configuration which can be tested by independent laboratories for the purpose of identifying (1) deficient areas at operation and (2) validating performance.

STAGE II - Based on inputs from independent lab tests conducted in Stage I, incorporate additional features and/or correct any deficiencies noted during various tests. Construct additional quantities of units incorporating agreed upon changes and re-submit to independent testing laboratory to verify performance of revised units.

STAGE III - Based on positive results from testing conducted in Stage II, incorporate additional changes required and construct a larger number of units for commercial field demonstration and testing.

Accordingly, the initial units are intended for limited prove up tests and are not necessarily the units which will eventually be manufactured for field test.

INSTALLATION: The ballast is mounted in an aluminum housing approximately 6 5/8" (16 cm) long x $4\frac{1}{2}$" (10.9 cm) wide x 4.0" (10 cm) high. The housing has mounting holes in the same locations as the existing core-coil ballast and is designed to fit in a standard Industrial HID fixture.

The ballast consists of three printed circuit boards as follows:

1) Lamp Drive Module

2) Power Supply Board

3) Master Board

Both the Lamp Driver Module and the Power Supply Board plug into the Master Board via standard TRW/Cinch PCB 22 pin connectors.

The Master Board is secured to the housing using standoffs. Additionally, two main power semi-conductors are secured to the bottom of the housing via screws and are replaceable in the event of a malfunction.

CAUTION

> The Power semi-conductors are live parts and it is possible to receive an electric shock between the case of the semi-conductors and the chassis or ground.

There are eight wires coming from the ballast which have the following functions. (Please refer to Drawing No. EXD 8661-01)

BLACK	-	AC+
WHITE	-	AC-
RED	-	LAMP, CENTER
YELLOW	-	LAMP, BASE
BROWN	-	)
PURPLE	-	) TO STANDBY BATTERY) MODULE
GREY	-	CONTROL REFERENCE
ORANGE	-	EXTERNAL CONTROL

LIST OF RECOMMENDED EQUIPMENT:

Input Transformer:	Jefferson 211-681 120/120/240/240 1.5 KVA or equal
Variac:	Superior Power-Stat Model 116B
Oscilloscope:	Tecktronic 465B or equal
Wattmeter:	Valhalla Scientific Model 2000 or equal
True RMS Meter:	Fluke 8921A
Resistor:	1 ohm non inductive watt resistor
Light Meter:	Tecktronic J16
Current Probe:	Tecktronic Model AM 503 with power supply

CAUTION: It is imperative that "sneak" ground paths or references be completely eliminated from the test setup by disconnecting the third (ground) wire from each peice of test equipment.

Because the ballasts are early experimental prototypical models, the case may or may not be electrically live. The operator is cautioned to ground the case directly to building or earth ground.

INITIAL CHECK:

With the initial set up shown in Figure I and the ballast disconnected, make sure that the powerstat/transformer is phased correctly and is registering the correct amount of voltage on the wattmeter/voltmeter. The Valhalla unit is recommended because it is inexpensive, reasonably accurate, and has a built-in ampmeter and voltmeter. If the test set up is wired correctly, the variac should be adjustable from essentially zero volts to well over three hundred fifty volts.

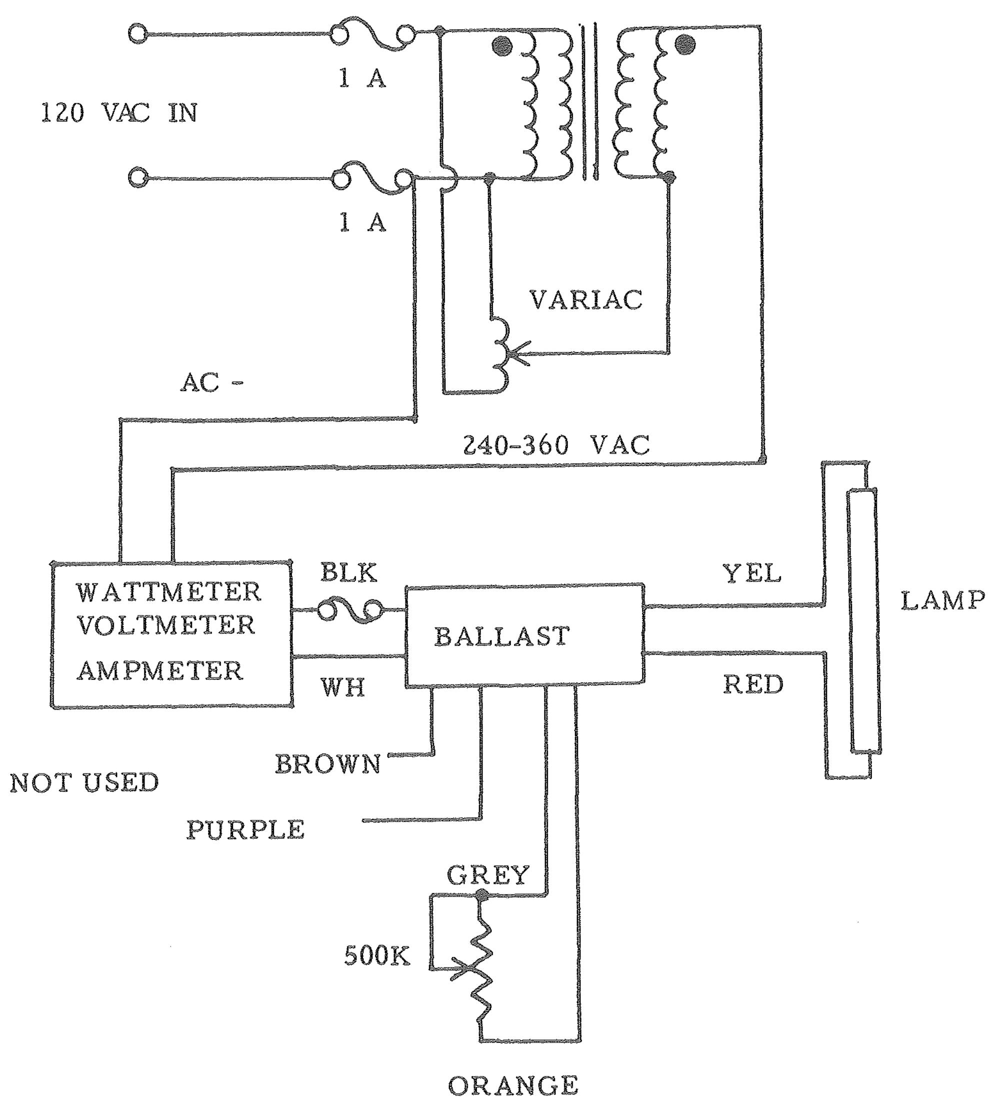
With the power off, connect the ballast input to the output of the 0-350 VAC power source and the lamp and control leads as shown. Slowly bring the voltage up and note that the lamp should light between 190 and 220 VAC IN, and that the wattmeter is registering power consumed. Increase the input voltage to 277 volts (note that the power to the lamp is relatively independent of line input changes from 250-305 volts and that from 235-250 volts, the ballast will still operate satisfactorily.

Note: All wires are electrically live and should be terminated to an insulator when not in use.

The ballast has two fuses. The first is a two (2) amp, 250v, fast blow fuse located in an inline fuse holder in the black AC input lead. The second fuse is also a two (2) amp, 250v, fast blow fuse connected internally within the unit and is used to protect the large power supply semi-conductor should a malfunction occur.

PREFERRED TEST SET UP:

The ballast should be set up for bench testing in the following manner:



Allow the lamp to warm up fully and adjust its light output using the external 500k potentiomenter connected between the grey and orange wires.

RECOMMENDED MEASUREMENT:

Power Factor (P^f) - measure P^f by one of two methods.

The first method is a direct calculation from the wattmeter input readings and is calculated by

$$P^f = \frac{W}{(E \times I)}$$

The second (and more accurate) method is to insert the 1 ohm non-inductor resistor in series with the AC + line and measure the voltage drop across the resistor. Calculate RMS current and multiply by input volts to get E x I and divide into Wattmeter reading.

Note: - This method should also be used when measuring lamp watts. The wattmeter cannot be placed directly in the output circuit because of loading considerations. One must look at the output wave forms to be assured that both E and I are in phase and not distorted. In this case lamp voltage is measured directly across the lamp.

The remaining measurements can be made directly from the test set up descirbed in Figure I and should include at a minimum:

1) Power factor at both high and low line with high and low light output.

2) Line regulations 250 - 305 and 235 - 305 volts AC in.

3) Dimming range.

4) Lamp Voltage

5) Open circuit lamp voltage (be careful of Striker pulse)

6) Striker peak voltage and wave shape

7) Flicker index use a fast response photocell

8) Output wave form modulation

9) Input and output current voltage waveforms

10) Lamp power regulation as a function of lamp voltage (trapezoid test to simulate aging).

11) Absolute power in Vrs light output (efficiency rating at various lamp voltages).

12) Spectral composition at dimmed level (with additional equipment)

13) Output frequency of lamp drive